# ALTERNATIVE TRANSPORTATION FUELS IN CANADA

Charles Slagorsky

CANADIAN ENERGY RESEARCH INSTITUTE

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## Preface

Most of the work on this study was carried out during the second half of 1981. Although falling prices of crude oil on the international market in the spring of this year suggested that alternative transportation fuels were becoming less attractive, the feeling now is that the world oil glut was only a temporary phenomenon. The security of foreign crude oil supply remains uncertain, making the study of alternative fuels an interesting and necessary inquiry.

During my work I have greatly benefited from discussions with experts in industry and government. Their help was essential in completing the study. I also wish to express an appreciation of their help to my colleagues at the Institute, and to two reviewers who read an earlier draft and made a number of suggestions for improvement. The last word of thanks goes to those who, with cheer, brought this work to the final draft: Carol Adams, Dorothy Denike, Shirley Ingstrup, Janice Tener and Arlene Ward.

# Chapter 1

## INTRODUCTION

Alternative transportation fuels other than those derived from crude oil began to attract increasing attention throughout the 1970s as a result of changes in economic and political circumstances during that time. The rising price of oil on both the international and domestic markets has naturally led consumers to seek alternatives whose prices have become (or are becoming) competitive with the price of oil. Furthermore, the supply of the substitute fuels is considered as being more secure in the light of possible crude oil embargoes, as long as they are manufactured from indigenous resources.

In Canada, the immediate alternatives to crude oil are the large oil sands deposits. The focus of this study, however, is on other alternative transportation fuels of which Canada may also have sufficient supplies. Particular attention is given to the supply and demand potential of the alternative fuels considered, especially in those regions of Canada where no hydrocarbon resources exist or where their consumption is greater than their production. In those regions, alternative fuels hold a special appeal since their production would not only lessen the dependence on often imported crude oil, but also create new investment and local employment opportunities. For Canada as a whole, the production of alternative fuels would imply the development of a production technology, which is a marketable commodity in itself,[1] and the establishment of an export potential once the production of substitute fuels exceeds domestic needs.

Among the alternative transportation fuels most frequently discussed today are methanol, ethanol, propane, compressed natural gas, liquefied coal and hydrogen. The objective of this study is to assess, on the basis of available information, (i) the economic viability of these fuels relative to crude oil, and (ii) an outlook scenario for supply and demand of the alternatives in Canada during this decade.

Chapter 2 contains an executive summary and the main conclusions of the study. In Chapter 3, the alternative fuels are described, their uses specified, and consideration given to the domestically available resources from which they could be produced. Chapter 4

contains an economic assessment of the substitute fuels for use in transportation. Different sources of production are considered, and their effects on the unit costs of producing such fuels are examined. Estimates of the cost of switching from the use of one fuel to another are also presented.

A possible supply and demand outlook for the new fuels is discussed in Chapter 5.

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[1]Provided that the alternative fuel is based on a resource that is global or is available in other countries.

## Chapter 2

## EXECUTIVE SUMMARY

As the price of oil on the international market has increased following the 1973-1974 oil embargo, alternative fuels to those derived from crude oil have become more and more economic. If economically viable, a switch away from crude-oil-derived fuels to alternatives would also increase energy supply security (as long as the new fuels are produced from indigenous resources) and enhance Canada's chances to become self-sufficient in oil.

The main objectives of this study have been to assess the economic viability of six alternative transportation fuels (methanol, ethanol, propane, compressed natural gas, liquefied coal and hydrogen), and to present a possible supply/demand scenario for four of these fuels in Canada during this decade.

Each of the selected fuels has been reviewed with regard to their physical properties, usefulness in transportation and methods of production from resources available in Canada. It appears that there are ample resources available in this country for the manufacture of the alternative fuels studied. In fact, Canada is in a position--enviable among western industrialized countries--to choose among the alternatives. Of course, choices will also have to be made with respect to the actual ways of utilization (viz. methanol).

A vital part of the study is the economic assessment of the selected fuels. Although the fuel cost estimates are only tentative, interesting conclusions can be drawn. The cost estimates have been compared to the current price of gasoline, based on both the Canadian and the world price of crude oil, as well as to the estimated cost of synthetic crude oil (oil sands). In undertaking the comparison, all costs of utilizing the alternative fuels in the transportation sector (e.g. the cost of engine conversion) were included and the fuels thus compared on an equal basis.

It turns out that, in Canada, we have two short-term alternative fuels--propane and compressed natural gas--which are available in sufficient quantities and at a lower cost than the current comparable cost of regular gasoline. Indications are that some motorists in large Canadian cities have already begun switching to these fuels.

There are two other alternatives available for the medium term--methanol and liquids from coal--which could be used in an interim period during which the entire energy base might be changed from non-renewable hydrocarbons, if and when such a change were timely and appropriate. The production of ethanol appears to be too costly relative to the other alternatives, and the cost of using hydrogen in transportation on a wide scale is at present simply too uncertain to be specifically compared to the other fuels.

Since there are two ways of using less gasoline (to switch to other fuels and to produce more fuel efficient vehicles), the cost estimates of producing alternative fuels can be compared to the cost of gasoline savings from improved vehicle fuel efficiency. This is a useful exercise because, if the two methods of reducing gasoline consumption are viewed as competing investment opportunities, their cost estimates are necessary for making the required capital investment decisions.

It has been estimated that during the short-term future (approximately until 1987), it would be more economical to improve fuel efficiency than to switch to alternative transportation fuels on a large scale, particularly in eastern Canada. For certain fleet operators, however, converting to propane or compressed natural gas is economical now, and their pay-back periods for the conversion cost could be as short as one year, after which significant savings in terms of reduced operating costs could be realized. Relative to the other fuels, propane and CNG are also the only two close to having distribution networks in place.

In terms of supply, Canada has a large potential to produce sufficient amounts of methanol, ethanol, propane and CNG for use as transportation fuels. But the analysis has shown that only CNG would be free of any restrictions in the main consuming areas if an alternative fuel were to be used on a significant scale in the near future.

# Chapter 3

# ALTERNATIVE LIQUID FUELS

## 3.1 Introduction

Six alternative fuels are considered here: methanol, ethanol, propane, compressed natural gas, liquefied coal and hydrogen. Recently, great attention has been given to the production and utilization of methanol, ethanol and liquefied coal. Hence, much more information is available with respect to these fuels than with hydrogen, for instance, which is still being considered by some as an exotic fuel that will not be utilized on a large scale until well into the next century. Each of the six alternative fuels are examined below with respect to their characteristics, methods of production from Canadian sources and possible ways of utilization in Canadian fuel markets.

## 3.2 Methanol and Ethanol

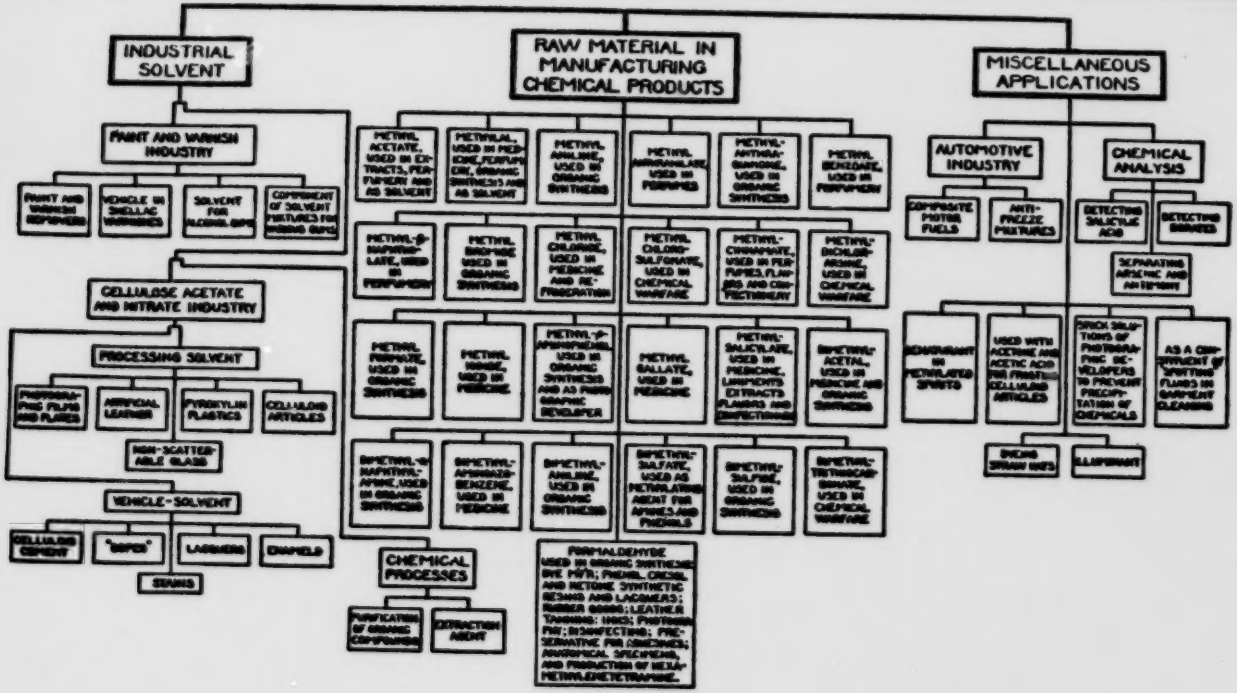
Methanol and ethanol are the two most frequently discussed alcohol fuels. They can be derived from various sources. The technology of producing them is well known and has been employed for many years. Widespread utilization of methanol and ethanol as fuels, however, has up to now been prevented by the availability of the relatively cheaper fuels derived from crude oil. Methanol ($CH_3OH$) has been produced on a large scale but while the production technology is well known, the end-product has been chemical methanol, not methanol as a fuel.[1] The limited usage of methanol (as fuel) up to now is attributable more to weak demand than to supply limitations.

Methanol is a toxic liquid which, like gasoline, becomes explosive when mixed with air. It can be derived from practically any material containing carbon, including natural gas, coal, forest products, agricultural products, peat and municipal solid waste. It should be noted that all of these sources are available in Canada. The largest chemical end-use of methanol is in formaldehyde.[2] Other chemicals derived from methanol include dimethyl terephthalate, methyl halides, ethylene glycol, methyl esters and acetic acid. Among the direct uses of methanol are fuel anti-icer, fuel cell component, fuel additive for rocket, jet and combustion engines, purification of coal, coal tar and gaseous and liquid hydrocarbons, in plastics, metallurgy,

as seed disinfectant, a hydraulic cement retarder and as a leading agent for uranium ore processing. Figure 3.1 provides a more complete picture of the various methanol end-uses. Methanol is currently not being utilized much as a fuel for transportation, space heating or electric power generation. In transportation, methanol blended with gasoline could be used in cars, or as a straight methanol fuel. When blended with gasoline, methanol could be expected to yield on combustion the same energy efficiency as would the displaced gasoline.[3] One of the main difficulties of using the gasoline/methanol blend, however, is the possibility of the two components of the blend separating, especially under cold conditions such as winter driving, or when exposed to small amounts of water. Nevertheless, a number of successful vehicle tests have been performed using methanol blends in special aromatic base gasolines with cosolvent alcohols to prevent phase separation. Vehicles powered by a methanol/gasoline blend would have to have supplemental tanks of propane or butane installed to assist in starting and carburetors would have to be modified to provide proper air/fuel ratios. The use of methanol in racing cars is also well established.

Using straight methanol would increase engine efficiency relative to gasoline by about 25 percent on a volume basis, but methanol has only about 48.5 percent of the energy content of gasoline per volume.[4] A major disadvantage of methanol, therefore, is that, relative to gasoline, the consumption rates would be higher. To allow an equal driving range, fuel tanks would have to be almost twice the size, requiring corresponding increases in the handling capacity of the distribution system. For the ordinary motorist, using straight methanol would improve acceleration, the engine would be lighter, it would burn without misfiring and with lower emissions, and the running on after the ignition switch is turned off would be eliminated because of the higher heat of methanol evaporation. Improved engine efficiency would also result from the possibility of late spark timing due to the higher flame speed of methanol.

One further option of using methanol in transportation is the Mobil Oil's conversion process of methanol to gasoline (MTG). In the MTG process, methanol is converted catalytically to gasoline-type compounds and water.[5] The resulting high quality unleaded gasoline has an octane number of 96 and it burns more cleanly than conventional gasoline since it contains no nitrogen or sulphur. About 2.5 litres of methanol are needed to obtain one litre of gasoline. The conversion process is about 70 percent efficient in obtaining gasoline from methanol. The efficiency is higher, however, ranging between 85 and 90


INDUSTRIAL SOLVENT
PAINT AND VARNISH INDUSTRY
PAINT AND VARNISH REMOVERS
VEHICLE IN SHELLAC VARNISHES
SOLVENT FOR ALCOHOL-SOL.
CONSTITUENT OF SOLVENT MIXTURES FOR VARIOUS USES
CELLULOSE ACETATE AND NITRATE INDUSTRY
PROCESSING SOLVENT
PHOTOGRAPHIC FILMS AND PLATES
ARTIFICIAL LEATHER
PYROXYLIN PLASTICS
CELLULOID ARTICLES
NON-SCATTERABLE GLASS
VEHICLE-SOLVENT
CELLULOID CEMENT
"DOPES"
LACQUERS
ENAMELS
SEALERS
RAW MATERIAL IN MANUFACTURING CHEMICAL PRODUCTS
METHYL ACETATE, USED IN EXTRACTS, PERFUMERY AND AS SOLVENT
METHYLAL, USED IN MEDICINE, PERFUMERY, ORGANIC SYNTHESIS AND AS SOLVENT
METHYL ANILINE, USED IN ORGANIC SYNTHESIS
METHYL ANTHRANILATE, USED IN PERFUMES
METHYL-ANTHRAQUINONE, USED IN ORGANIC SYNTHESIS
METHYL BENZOATE, USED IN PERFUMERY
METHYL-β-NAPHTHYLATE, USED IN PERFUMERY
METHYL BROMIDE, USED IN ORGANIC SYNTHESIS
METHYL CHLORIDE, USED IN MEDICINE AND REFRIGERATION
METHYL CHLOROSULFONATE, USED IN CHEMICAL WARFARE
METHYL-CINNAMATE, USED IN PERFUMES, FLAVORS AND CONFECTIONERY
METHYL-DICHLOR-ARSINE, USED IN CHEMICAL WARFARE
METHYL FORMATE, USED IN ORGANIC SYNTHESIS
METHYL IODIDE, USED IN MEDICINE
METHYL-β-NAPHTHYLAMINE, USED IN ORGANIC SYNTHESIS AND AS PHOTOGRAPHIC DEVELOPER
METHYL SALICYLATE, USED IN MEDICINE
METHYL-SALICYLATE, USED IN MEDICINE, LINIMENTS, EXTRACTS, FLAVORS AND CONFECTIONERY
METHYL-SULFATE, USED IN ORGANIC SYNTHESIS AND MEDICINE
DIMETHYL-β-NAPHTHYLAMINE, USED IN ORGANIC SYNTHESIS
DIMETHYL-AMINO-BENZENE, USED IN MEDICINE
DIMETHYL-ANILINE, USED IN ORGANIC SYNTHESIS
DIMETHYL-SULFATE, USED AS METHYLATING AGENT FOR AMINES AND PHENOLS
DIMETHYL-SULFIDE, USED IN ORGANIC SYNTHESIS
DIMETHYL-THIOCARBAMIDE, USED IN CHEMICAL WARFARE
CHEMICAL PROCESSES
PURIFICATION OF ORGANIC COMPOUNDS
EXTRACTION AGENT
FORMALDEHYDE
MISCELLANEOUS APPLICATIONS
AUTOMOTIVE INDUSTRY
COMPOSITE MOTOR FUELS
ANTI-FREEZE MIXTURES
CHEMICAL ANALYSIS
DETECTING SALICYLIC ACID
DETECTING SUGARS
SEPARATING ARSENIC AND ANTIMONY
DENATURANT IN METHYLATED SPIRITS
USED WITH ACETONE AND ACETIC ACID FOR PRINTING CELLULOID ARTICLES
SPECIAL SOLUTIONS OF PHOTOGRAPHIC DEVELOPERS TO PREVENT PRECIPITATION OF CHEMICALS
AS A CONSTITUENT OF "SPOTTING" FLUIDS IN GARMENT CLEANING
ENEMA SPRAY NOZZLES
ILLUMINANT

SOURCE: A. Lowy and B. Harrow, An Introduction to Organic Chemistry. New York: J. Wiley & Sons, Inc., 1940, p. 58.

FIGURE 3.1: USES OF METHANOL

percent, for the conversion of methanol to fuel products including gasoline, olefins and liquefied petroleum gas (LPG) components. The only potential problem of the MTG process is the presence of a substance (durene, $C_{10}$ alkylbenzene) which can crystallize in the carburetor and cause clogging.

In space heating, methanol has the potential of being a more efficient furnace fuel but since methanol's vapors are highly toxic, a safe storage system would have to be designed before it could be used on a large scale, particularly for home heating. Owing to the problems facing the users of methanol blends in transportation, it is possible that, in certain locations, large electric power stations could be the first significant users of methanol as a fuel. Thermal power stations have a large, continuous and dependable demand for fuel, and burning of methanol instead of fuel oil would call for no major retrofit, except for a change of nozzles of large boilers.[6] Methanol could also be used to replace water in coal slurry pipelines and be burned at the receiving end.

Ethanol ($C_2H_5OH$) appears economically much less attractive than methanol but its calorific value is greater. It is produced by hydrolysis and fermentation of biomass feedstocks while methanol is made by synthesis over catalysts of carbon monoxide and hydrogen. Ethanol production by fermentation has four basic stages: (i) processing of feedstock to obtain sugar solution; (ii) conversion of the sugar to ethanol and carbon dioxide through the use of yeasts or bacteria, (iii) ethanol is distilled from the fermentation solution; and (iv) removal of water to yield purer ethanol.

Alcohols have very high research and motor octane values (around 106). With the pressure on to remove heavy metals from gasoline and the declining octane number of the motor gasoline (MOGAS) pool, alcohols are being seriously considered for use as octane boosters. It can be argued that in such use, alcohols command a significantly higher value than that suggested by their energy content. On volume basis, ethanol has an energy content of about 30 percent higher than methanol. Ethanol also shows better compatibility with other hydrocarbon fuels, such as gasoline. This makes it a more suitable fuel for blending than methanol. The blend of 90 percent gasoline and 10 percent ethanol known as 'gasohol' is now popular in the U.S. and becoming so in Canada since no engine modifications are required for existing automobiles. Gasohol can be burned in conventional automobile engines with a slight loss in fuel efficiency (0 to 4 percent) and a

slight gain in octane rating. The penalty in fuel efficiency tends to be more noticeable in later model cars.

The prime obstacle to wider utilization of ethanol is the very high cost of feedstocks which include foodstuffs (grain, sugar beets, etc.). This competition for the use of agricultural output, and the net energy balances of known ethanol production processes will likely restrict the use of ethanol as a fuel to that of an 'extender' of conventional automotive fuels. Ethanol cannot be viewed, therefore, as a true alternative fuel. No engine modifications are needed for less than 10 percent alcohol/gasoline blends. When used as an extender to gasoline, alcohol (ethanol or methanol) also boosts the octane rating of the blend. Ten percent of ethanol in unleaded gasoline increases the octane number roughly by 2 to 3 points, with similar enhancement of the octane rating available through the use of methanol.[7] The octane-boosting properties of alcohol fuels are especially attractive where the use of other octane enhancers such as MMT (methylcyclopentadienyl manganese tricarbonyl) or lead (tetra ethyl) is restricted due to, for instance, environmental considerations.[8] The economic cost of increasing the octane number through the use of alcohols, however, is likely to be the highest of other methods such as lead addition (low cost) or high severity processing in the refinery (medium high cost).

One further general advantage of alcohols is that they contain no lead or sulfur and thus there are no emissions of sulfur dioxides. Both alcohols burn cleanly without depositing carbon, and at lower temperatures than other fuels which decreases the presence of nitrogen oxides. In higher concentrations, alcohol fuels permit the use of more efficient engines with higher compression ratios (racing cars often run on pure methanol) than gasoline engines. Although methanol is toxic, in the case of a mishap such as tanker spill, there would be no oil slick and no fire since methanol and water are miscible. Methanol can also be easily transported by pipeline, rail or conventional tank truck.

The main difficulties associated with alcohol fuels, and methanol in particular, centre around the following five problems:[9] (i) methanol solubility in gasoline, (ii) phase separation, (iii) incompatibility with certain materials due to corrosion, (iv) increased aldehyde emissions, and (v) potential customer dissatisfaction with some performance characteristics of methanol.

'Phase separation' is one of the major problems associated with the use of methanol/gasoline blends. It occurs when, in the presence

of small amounts of water and under cold conditions, the two components of the blend separate in layers. Water is fully miscible in methanol and methanol is miscible in gasoline up to 10 percent in volume. When water is added to a mixture of methanol and gasoline, the water methanol phase separates and settles at the bottom of the storage tank. Since small quantities of water are frequently present in fuel distribution facilities, phase separation could cause serious problems. A non-combustible mixture of water and methanol settles where fuel intake usually originates (at the bottom of the tank), which will result in either stalling or starting problems. Among the suggested solutions is to increase the content of higher alcohols and aromatics in the blend which would improve the blend's tolerance to water. A second solution could be to make the fuel distribution system (including storage tanks) totally resistant to water penetration. Since the latter solution may be costly, we could expect some compromise, such as having both a waterproof methanol system and a parallel conventional gasoline system with the fuels being mixed only just before entering the carburetor.

Vehicles may also experience problems in cold temperature starting. Engines powered by pure methanol will not start at temperatures below 10°C. Low temperature can further cause a phase separation to occur even in the absence of water. There are two possible solutions to the cold temperature starting. The first is the use of a separate source of gasoline just to start and warm up the engine. The second is the addition of 10 percent i-pentanes in the blend which would permit starting at temperatures down to -25°C. The phase separation would, of course, not occur if straight methanol were used instead of a blend.

A related problem to phase separation is that of a 'vapour lock', also resulting from blending gasoline and methanol. Vapour lock occurs when increased vapour pressure in the blend causes the gasoline to vapourize in the fuel pump, blocking the flow of fuel. A possible solution to this problem would be removal of the more volatile components of gasoline at the refinery stage.

Another problem is that of corrosion. Whether used as a straight fuel or in a blend, methanol can cause significant corrosion in such standard engine parts as gaskets and elastomer seals. In addition, methanol causes corrosion of aluminum, lead and zinc-coated iron. The problem could be eliminated by either the addition of appropriate inhibitors or by a specially designed methanol-powered engine

which would not use metals and plastics subject to methanol corrosion.

Methanol/gasoline blends significantly reduce most exhaust emissions compared with those of gasoline, but the blends may increase the amounts of aldehydes emitted. Although little is known about the effects of these emissions, it has been postulated that they would rapidly oxidize in the atmosphere.[10]

The last of the difficulties listed above relates to consumers' satisfaction and acceptance of alcohol fuels or blends of alcohol and gasoline. It would appear that the relative cost of running a car on a methanol/gasoline blend or gasoline would be the prime determinant of consumers' acceptance of the new fuel. As far as satisfaction is concerned, much will depend on the type of automobiles and the driving habits of the users. Generally, cars running on a richer air/fuel ratio will exhibit no change in performance, whereas cars tuned-up to use a leaner mixture could experience difficulties such as stalling, surges, loss of throttle acceleration or poor warm-up characteristics at low temperatures.[11] Owing to the higher octane rating of alcohol fuels, however, a quicker and more powerful response to the accelerator can be expected. Methanol has an octane rating of 106, compared with typical gasolines of 85 to 100. On the whole, neat alcohol exhibits superior combustion properties when compared with either gasoline or methanol blends, but engine modification of existing cars would be required.

The one country where, due to the lack of indigenous energy resources, the greatest advances have been made in the use of alcohol fuels in transportation is Brazil.[12] The first phase of Brazil's National Alcohol Program (a nation-wide use of gasohol containing 20 percent ethanol) has almost been achieved and the country is about to begin the second phase--a widespread utilization of neat alcohol fuels in transportation and elsewhere. In 1979, about 14 percent of total gasoline demand in Brazil was displaced by alcohol added to gasoline and some 4,000 vehicles were running on neat ethanol. Future plans call for 300,000 new neat ethanol cars by the end of 1981 and 350,000 by 1982. Together with retrofitted automobiles, some 1.2 million vehicles (10 percent of total) should be running on neat ethanol in 1982.

In Canada, motorists will be using the mixture of ethanol (10 percent) and unleaded gasoline (90 percent) before either methanol or neat ethanol since no engine modifications are required when using the gasohol mix. Mohawk Oil Company has converted a distillery in

Minnedosa, Manitoba to produce some 7.95 million litres of ethanol per year, using feed-grade barley as feedstock with the possibility of switching to corn or other grains if supply conditions become favorable. There are, as well, a number of pilot projects under development in Ontario and Manitoba. Also under consideration are small, on-farm distillation outlets utilizing agricultural surpluses or wastes in producing ethanol. The alcohol fuel thus manufactured could be used to run farm machinery. If this kind of alcohol production was to proceed on a large scale, however, new problems would have to be overcome, not the least of which could be that of control, including bonding.

### 3.3 Propane

Propane ($C_3H_8$) is a gas which is easily liquefied under moderate pressure. It is an excellent fuel of which Canada currently produces an exportable surplus that could be used domestically to lessen our dependance on imported crude oil. In 1980, an average of about 20 600 $m^3$ (130,000 barrels) per day of propane were produced in Canada but the highly seasonable domestic demand averaged just below 7 950 $m^3$ (50,000 barrels) per day. Only 2 percent (159 $m^3$/day) of the domestic demand were used as motor fuel; the rest was mainly used in industry for heating, for petrochemical feedstock or for solvent flooding in enhanced oil recovery schemes. It can be shown that if 500,000 highly travelled vehicles (for e.g., 32 000 km/year, using 22.4 L/100 km) were converted to the use of propane, daily demand for propane would increase by about one half of current Canadian output (9 880 $m^3$), still leaving a small amount for export. Assuming a 31 percent gasoline yield per each $m^3$ of crude oil refined, this conversion would represent a crude oil savings in the order of 31 780 $m^3$ (200,000 bbls) per day.

The use of propane, compressed natural gas or other liquefied petroleum gases in transportation on a moderate or large scale may be new in Canada, but is it not new in other parts of the world. Countries like the Netherlands or Italy have a long history of using these fuels and thus, with suitable modifications, the use of standards and other valuable experience could be adopted in Canada. Like alcohols or alcohol/gasoline blends, these fuels only require demonstration of their suitability to the needs of the Canadian transportation sector before they could be adopted and implemented within this decade.

Most of Canada's propane is produced in natural gas plants and stripping plants in western Canada, while smaller amounts are produced at refineries across the country. Propane is heavier than air and can

thus be trapped by gravity in open containers or low areas and is, accordingly, a different type of hazard than gasoline in the event of fire.

As an alternative fuel, propane is expected to displace crude-oil derived products mainly in transportation. Engine modifications will be required before an automobile can switch from gasoline to propane. Initially, with some modifications, cars can be fitted to use either propane or gasoline. Vehicles designed for the exclusive use of propane have been developed. For example, the Honda Motor Company produces a propane-powered car used in taxi fleets in Tokyo, and the company would be prepared to export the cars if market conditions were suitable.[13] In North America, the Ford Motor Company is presently manufacturing propane fuel systems on a limited basis,[14] and Lada Cars of Canada (marketing the USSR-made automobile) is offering a dual gasoline and propane-powered car.

A vehicle converted to exclusive use of propane has all carburetion equipment removed which increases simplicity and reliability. A larger, pressurized propane fuel tank must be installed, restricting usable cargo space. Depending on their capacity, the propane tanks may weigh between 50 and 180 kilograms (110 to 400 lbs.) and provide a driving range of around 400 km (250 miles). At the time of writing (late-1981), there were some 36 refuelling stations in Calgary. Refuelling of propane-powered vehicles will require either the assistance of experienced staff or modifications allowing safe refuelling procedures, especially at self-serve stations. Since propane is refuelled under pressure (120 to 160 psi), a screw-on fitting to the tank will have to be used and safety procedures closely followed. With some safety features added, however, propane fuelling would on the whole be at least as safe as gasoline even though, because of the pressure involved, somewhat more complicated.

From experience gained by users of propane as a transportation fuel in Canada and the U.S., several areas of concern have been identified.[15] The first pertains to ignition timing. The problem here originates from the fact that most propane conversions have been carried out in such a way that both propane and gasoline can be used (dual-fuel system). Although propane has a higher octane rating (97) than gasoline (85), the efficiency of the former is lower than that of the latter, unless the engine is specifically tuned to operate exclusively on propane. Only about 85 percent efficiency can be expected from burning propane in an engine that is tuned to use either of the two fuels. On the other hand, when propane conversions include adjustment of static ignition timing to optimize operation on propane,

performance when running on gasoline is also degraded. This means that an engine tuned to run on propane only will exhibit mileage about equal to a gasoline engine (litre for litre), while a vehicle set to run on either of the two fuels will operate less efficiently when using any one of the fuels. (For more details, see footnote 16, Chapter 4 below.)

The second area of concern is that of selecting the proper ignition system. An engine operating on propane tends to be more sensitive to misfiring and to other malfunctions of the ignition system. Problems of this kind seem less frequent with more recent engine models using a specially designed ignition (capacitive discharge).

The third problem is cold starting. Propane will not vaporize at temperatures below -40°C and thus starting problems may be experienced during winter months. Up to this time, however, no major difficulties have been reported by users, due largely perhaps to the possibility of starting the engine on gasoline and then switching to propane once the engine has warmed up. Generally, an engine should start on propane as long as there is some gaseous propane left in the fuel line even if the gas pressure is low.

The fourth problem involves the actual switching between the two fuels in a dual-fuel vehicle. The process of switching consists of turning off the gasoline, once the motor has been started, running the carburetor dry and turning on propane just before the engine dies, or restarting then. Experienced users may have no problems with this procedure but new users could find it troublesome.

On the whole, users of propane may find the fuel no less convenient or safe once distribution centers are more numerous and engine conversions can be done quickly and economically. As will be shown in the following chapter, the present differential between the prices of propane and gasoline is such that the switch to propane is economically viable. Since the market acceptance of propane is primarily determined by such a price differential, the future of propane as a fuel in transportation will depend on the movement of the price of propane relative to gasoline. With respect to the alcohol fuels, propane appears to be both more readily available and usable. These advantages make it a better candidate for an alternative transportation fuel during this decade than either methanol or ethanol. It must be recognized, however, that propane is a non-renewable hydrocarbon fuel and hence, unlike methanol and ethanol, not a true long-term alternative to the crude oil-based fuels used today. It could best be used as a fuel

during the 'off-oil' transition period when existing automobiles could use it with only slight modifications.

### 3.4 Compressed Natural Gas

Compressed natural gas (CNG) is another alternative fuel, with applications especially in transportation, which has recently attracted increasing attention. This is because the technology of producing and using CNG is well known and has been utilized for several decades and, importantly, because Canada currently has a surplus of natural gas which is forecast to prevail in the foreseeable future.

As of the end of 1980, the Canadian reserves of marketable natural gas stood at 2 492 billion cubic metres (88 TCF)[16] and it has been estimated that approximately 500,000 vehicles travelling long distances could be powered by only 2.83 billion cubic metres (0.1 TCF) for one year.[17] This conversion would in turn imply savings of nearly 31 780 $m^3$ (200,000 bbls) per day of crude oil equivalent. A wide-spread conversion to CNG would therefore not threaten existing supplies of natural gas with depletion, and it would not be expected to put an undue pressure on the supply price of natural gas.

The predominant (around 95 percent in the case of Alberta reserves) component of natural gas as it is found in the ground is methane. In addition, there are often higher hydrocarbons present including pentanes and ethane as well as hydrogen sulphide (sour gas). Natural gas is frequently processed to remove the $H_2S$, capture the condensates (pentanes) for gasoline use and to isolate the ethane as a basis for the ethylene industry. As a result, pipelines natural gas is frequently 98 percent or more methane. Synthetic natural gas can be obtained from coal, peat and wood gasification as well as from anaerobic digestion of animal and food wastes. Given Canada's coal reserves (see section 3.5 below) and her biomass potential, large amounts of this gas could be produced and consumed on a renewable basis.

Natural gas (methane) can be used as a transportation fuel, either as a compressed natural gas (in a gaseous form), or as liquefied natural gas (LNG). The reason for compressing natural gas or for liquefing it is to increase its energy 'density' per volume. When compressed, natural gas' energy content per volume increases about 200-fold, and when liquefied, it rises 600-fold. The physical properties of LNG, however, spell difficulties for handling the liquid. Both the cryogenic temperature of -162°C (-260°F) at atmospheric pressure and the low critical temperature of methane of -82°C (-166°F)

imply that LNG must be transported at a temperature ranging within these limits.[18] Thus although natural gas may be transported as LNG from remote producing areas of the Canadian Arctic to markets in the south, as a transportation fuel its best use will likely be in the form of CNG.[19]

Many research reports have been published showing the advantages of CNG as a fuel in transportation.[20] Although stored under high pressure (2400-3000 psi) in specially installed steel cylinders, CNG has a clear safety record in Italy, where it has been used in vehicles since the early-1920s and where currently some 260,000 vehicles are CNG-powered.[21] The fuel is non-toxic, lighter than air (causing it to rise and disperse rather than settle before evaporating like propane or gasoline), it burns more efficiently than gasoline and, due to the high octane rating of methane (130), vehicles using CNG may have higher compression ratios (in the order of 14 to 1) which improves engine performance.[22] Also maintenance cost is reduced since CNG burns cleanly, prolonging engine life.

The main disadvantage of CNG on the other hand, is that no existing vehicles can use it without an in-shop conversion and that outlets to refuel once conversion is made are at present very limited. As for future plans of the car manufacturers, a two-passenger prototype car fuelled by CNG has recently been announced by Ford Motor Company and will be shown at the 1982 World's Fair in Knoxville, Tenn. in May of this year. At present, driving range, on converted vehicles is still relatively short (maximum 240 kilometres or 150 miles on two CNG cylinders) which makes CNG more attractive for fleet operators with a central fuelling station such as taxis, delivery trucks, etc. Fuelling stations, however, could easily be set up along the already existing network of natural gas pipelines through the country. All that would be required is to connect a compressor station and simple refuelling outlets at any location in Canada where natural gas is being used. Thus an important part of the infrastructure is already in place. The main disadvantage of CNG then is the cost of conversion (discussed in the following chapter), which makes it possible to operate a vehicle on either gasoline or CNG with no difficulties associated with switching from one fuel to another while driving.

In Canada, experiments with CNG-powered vehicles date back some ten years. For example, the Canadian Western Natural Gas Company of Calgary has a CNG refuelling station for some 100 vehicles. Other more recent tests have been carried out by other parties including CNG Fuel Systems, Ltd. of Calgary, Consumer Gas in Toronto, the Cities of

Edmonton and Calgary, and B.C. Research. CNG Fuel Systems estimated that by 1986, 500,000 fleet and private vehicles will be converted to natural gas. A committee has also been established under the sponsorship of the Canadian Gas Association to draft a safety code for CNG refuelling stations and vehicle conversions.

Other options for natural gas have been suggested. Prominent among them is the previously mentioned method, developed by Mobil Oil, of making synthetic gasoline from natural gas via methanol (MTG). Natural gas is first converted to methanol which is then, through synthesis, transformed into synthetic gasoline. Clearly this is not a very energy efficient way of producing gasoline (56 to 58 percent) which has thus far been considered only in New Zealand where there are large natural gas deposits but no crude oil. The New Zealanders, however, are also involved in a significant way in converting some of their vehicles to CNG.[23] The one clear advantage of the MTG process is that no vehicle conversions are required, in fact the resulting synthetic gasoline contains fewer impurities and, with additives, its quality is similar to that of unleaded premium gasoline derived from crude oil.

In the case of the MTG process, however, natural gas (and methanol) are not really truly 'alternative' fuels (alternative to gasoline) since existing vehicles keep using the same fuel in an environment characterized by an absence of incentives to change to real longer-term alternatives. Hence while it may make economic sense to produce synthetic gasoline from natural gas (reserves of the latter permitting) during some transition period, it makes little energy sense because the process itself consumes too much energy. In strict economic sense, this situation can prevail only in the presence of price distortions. When one or more of the factors of production (land, labour, capital, energy) are artificially low priced--as is the case of energy in Canada--then more will be used to produce a given output.[24] This sort of reasoning applies not only to natural gas or methanol but to all other fuels considered in this chapter. Whether it is natural gas, electricity, methanol, hydrogen or any other fuel, due to the complexity of existing price regulations, the methods of production, distribution and the various types of end-uses, it is clear that a systematic approach to switching to alternatives based on sound economic principles is preferable. Considerations of cost are of course paramount, but one should not lose sight of the fact that longer-term supply availability is why considerations to the alternative fuels are being given in the first place. The MTG process could be viewed as a long-term alternative if the gas (to produce methanol) was generated on

a renewable basis from biomass, or from large coal reserves. The one clear advantage would be that we could keep on utilizing the extremely large sunk investment in the distribution network for gasoline as well as to continue using the current type of automobile.

### 3.5 Liquefied Coal

A conservative estimate of recoverable coal reserves in Canada is 16.1 billion tonnes.[25] Given these vast reserves, coal liquefaction has frequently been viewed as a promising source of indigenous alternative liquid fuels. The technology of liquefying coal is well known and has been utilized in various parts of the world since the early 1920s.[26] For example, in Germany and Japan during the Second World War, approximately 11 900 $m^3$ of gasoline from coal were produced daily, plus some 3 970 $m^3$ a day of diesel fuels. The coal liquefying process results in a wide range of products suitable for either further refining or an immediate use. Refining of coal liquids on a large scale, however, would require new refineries or substantial adjustments to existing ones. But, initially, a small quantity of coal liquids could be blended with conventional crude oil as refinery feedstock without great difficulties.

The object of the coal liquefaction process is to obtain a liquid product with a higher hydrogen/carbon ratio and lower average molecular weight than the parent coal. Coal is basically a hydrocarbon deficient in hydrogen and thus the liquefying process consists of either adding hydrogen or rejecting excess carbon. Coal can be converted to transport fuel, industrial fuel gas, synthetic natural gas (SNG) and solid fuels. The development of a liquefaction process which would result in a variety of fuels fitting the user's requirements is currently under way. The commercially mature indirect liquefaction process starts with gasification of coal to obtain synthesis gas, which is then converted to methanol, or to other liquid products through the Fischer-Tropsch synthesis (used in South African Sasol operations). A useful distinction can be made between this commercially mature indirect liquefaction process and the direct liquefaction process which is only at pilot and demonstration stages of its development. The only commercial coal liquefaction projects currently in operation are the Sasol I and Sasol II plants in South Africa. Sasol I has been operating since 1955. The recently completed Sasol II will be consuming 40 600 tonnes of coal daily, producing some 20 usable products including gasoline, diesel fuels and a variety of chemicals. Sasol III is in the planning stage with possible start up in 1990.

Current commercial processes for coal liquefaction have a relatively low thermal efficiency ranging from 40 to 45 percent.[27] Processes at the pilot project stage, however, have exhibited thermal efficiency as high as 65 percent. The range of the yield of liquids from one tonne of coal is between 0.28 and 0.44 $m^3$ (1.75 to 2.75 barrels), depending on the technology employed and the type of coal used.[28] The Sasol II plant will produce about 7 950 $m^3$ (50,000 barrels) of liquids per day and will require coal production of between 6.5 and 10.0 million tonnes annually (an annual output far beyond that of a typical Canadian coal mine). To minimize the cost of transportation of large quantities of coal, a coal liquefaction plant should be located near or at the mine site. It has been estimated that the development of a mine of appropriate scale, together with the concurrent building of a plant, would take some 10 years.[29]

There are four main methods of coal liquefaction.[30] These are (i) pyrolysis (or hydrocarbonization), (ii) solvent extraction, (iii) indirect liquefaction and (iv) catalytic hydrogenation.

(i) Pyrolysis is the rapid heating of coal in a closed system in the absence of air to produce liquids, gases and solid residue. Operation of the pyrolysis reactors is in the temperature range of 450°C to 600°C (842-1112°F) and at slightly above atmospheric pressure. Coal is first ground to fine particles and then in an inert atmosphere or in the presence of hydrogen, heat is applied to drive off water, gases and liquid hydrocarbons. Recovered oil is sent for hydrotreating to obtain either fuel oil or synthetic crude. Certain amounts of gas are also recovered. The gas is scrubbed of contaminants and can be used as plant fuel, feedstock for a hydrogen plant or simply sold as a by-product. The main product is char which requires gasification before clean fuels can be produced from it.

Processes using pyrolysis are especially attractive since the yield of liquids is maximized. The most technologically advanced pyrolysis process is the Lurgi-Ruhrgas process, which has been operating commercially in Yugoslavia since 1963 in a plant consisting of two trains each of the capacity of 800 tonnes of dry coal feed a day. The coal used is a lignitic brown coal. In this plant the oil product is mixed with the char product and the mixture is then used for coking coals in the manufacture of metallurgical-grade coke. The pyrolysis process (and specifically the Lurgi-Ruhrgas process) has been selected for detailed evaluation as one of the least-cost candidates for commercial coal liquefaction in Alberta.[31] Several companies, including

Occidental Petroleum, Rockwell International, Union Carbide and Lurgi are presently testing this type of process.

(ii) Solvent extraction, the second of coal liquefaction methods, can be accomplished in one of three ways: (a) hydrogenated solvent without hydrogen (used in the Consol Synthetic Fuel process--CSF); (b) hydrogen and non-hydrogenated solvent (used in the Solvent Refined Coal process--SRC by Gulf Mineral Resources Co.); and (c) hydrogen and hydrogenated solvent (used in the Exxon Donor Solvent process--EDS). The original process of solvent extraction involved employing a mixture of tetraline and cresol to dissolve up to 80 percent of the coal. The resulting product was a hard, brittle asphaltic mass, ash-free solvent-refined coal. The final product of the modern solvent refined coal (SRC) process is similar. The resulting solids do not have high enough value to be specifically produced but may be burned in utility boilers. The liquids produced by solvent extraction can be of high quality, particularly in the case of Gulf SRC II and Exxon EDS processes which have been successfully demonstrated.

The SRC II process starts by pressurizing a slurry of dry pulverized coal in recycled oil with hydrogen at 1500-2500 psi. The mixture is briefly preheated in a digestor to 370-400°C (690-752°F) in order to initiate thermal decomposition and exothermic dissolution of the coal material. The slurry is then transferred to a 'dissolver' where heat released by liquefaction is allowed to raise the temperature to 440-465°C (825-870°F) and excess heat is dissipated by injection of cold hydrogen. Overhead vapors generated in the dissolver are withdrawn through a series of separators and finally fractioned at atmospheric pressure into light and heavy oils, while liquids from the dissolver are taken to vacuum-distillation. As in other liquefaction processes, a portion of the distillates recovered from this unit is returned to the digestor for slurrying fresh coal and vacuum bottoms are gasified with oxygen to produce hydrogen for the process.

The EDS process liquefies coal by non-catalytic hydrogen transfer from recycled oil and regenerates the donor by hydrotreating and returning a portion of the coal liquids. The first step takes place in the dissolver where gaseous hydrogen and hydrogenated distillate oils interact with pulverized coal at 425-265°C (798-870°F) and 1500-2000 psi. The hydrogen atmosphere promotes dissolution of the coal substance by participating in the stabilization of free coal particles and extends the donor life of the oils by partly dehydrogenating the hydrogen-depleted liquids. The product mixture is then taken through heat exchangers and it is flashed to atmospheric pressure in order to

extract hydrogen and gases. After conventional hydrotreating, the material is fractioned to yield naphtha and heavier distillate oils of which a portion is returned to the dissolver for reaction with fresh coal. This procedure yields approximately 3 barrels of distillate oils per one tonne of dry coal. Since coal dissolution and upgrading can be conducted as independent operations, the final products are virtually sulphur-free oils.

(iii) Indirect coal liquefaction is the third main method of liquefying coal, and is at present the only method used commercially. It is achieved by gasifying coal to a mixture of carbon monoxide and hydrogen; from this a complex state of liquid hydrocarbon products is synthesized by the Fischer-Tropsch synthesis, or mostly gasoline obtained via the methanol route using the Mobil process.

The synthesis of liquid hydrocarbons from coal via a synthesis gas originated in the laboratories of BASF in Germany prior to the First World War. The process was improved by Fischer and Tropsch in the 1920s and perfected by Pichler who found a suitable catalyst for the synthesis. The process is capable of producing high octane motor fuel and diesel oil but its primary advantage consists in its ability to produce feedstock for fats, soaps and detergents. Although the economics of the Fischer-Tropsch process employed in South African Sasol plants is considered marginal in most other countries, it is nevertheless the only commercially operating coal liquefaction process in the world.

(iv) The fourth coal liquefying method is catalytic hydrogenation. It dates from 1913 when Friederick Bergius showed that brown coal could be converted into a heavy crude oil. This process was further developed by J.G. Farben in a large-scale developmental programme begun in 1927. By 1938, crude-oil-deficient Germany had increased its production capacity using this process to 85,000 barrels per day.

Following the 1973-74 oil price increases the J. G. Farben technology was further improved in Germany. The catalyst in this technology is not recoverable but a relatively inexpensive material (iron oxide in this case) is used. The process employing catalytic hydrogenation which has reached large scale development in the U.S. is the H-Coal process. The development was initiated in 1964 by Hydrocarbon Research Inc. as a modification of the H-Oil process designed to treat heavy oil fractions.

The core of the process is an 'ebullated bed' reactor in which a coal-oil slurry reacts with hydrogen-rich gas. Hydrogenation is

normally conducted at about 455°C (850°F) and 2500 psi with liquid yields of 3 to 4 barrels per ton of coal. Overall efficiency of the conversion of coal to oils and hydrocarbon gases is better than 90 percent.

In the presently favoured type of H-Coal process, oil vapors leaving near the top of the reactor are first cooled and depressurized in order to recover unreacted hydrogen and hydrocarbon gases. The vapors are then sent to atmospheric pressure distillation from which a synthetic light crude and heavy fuel oil fraction(s) are obtained. The heavy distillate oils produced are combined with a heavy fractions from atmospheric pressure distillation, and the vacuum bottoms are gasified with oxygen to produce the syngas which supplies hydrogen to the reactor. Both bituminous and subbituminous coals can be employed in the H-Coal process.

The research and development of coal liquefaction has not proceeded in Canada with the same sense of urgency as it recently has in some other countries, for instance in Germany, South Africa or the U.S. Only a few bench-scale projects exist, or are under construction in this country. Research effort to date, however, suggests that coal liquefaction, particularly in the provinces of Alberta, Saskatchewan or Nova Scotia may complement development of oil sands and heavy oil deposits and help to reduce Canadian dependence on foreign crude oil. Canada has abundant supplies of natural gas which can be used to manufacture the hydrogen required in a modern coal liquefaction process. This, together with truly large quantities of low quality coal offers a suitable process combination for a coal liquefaction development, especially in western Canada.

Among the current developments in coal liquefaction in this country are the efforts by Noval Technologies of Calgary, by a consortium of companies in British Columbia and the B.C. Government, and by a group of companies in Nova Scotia. Noval Technologies has been studying coal liquefaction since 1976 and is presently looking into the possibility of constructing a demonstration plant (probably of the capacity of 3178 $m^3$ or 20,000 bbls of synthetic oil per day) by the end of the decade or in the early 1990s.

In British Columbia, a consortium was formed in the summer of 1980 by the B.C. Resources Investment Corporation, Petro-Canada and Westcoast Transmission to develop a $4 billion to $5 billion coal liquefaction plant in the province. The actual construction is still years away, however, as the most suitable coal deposit and the type of liquefaction process must be determined. The provincial government is

also studying the possibility of a major coal liquefying plant near coal deposits at the Hat Creek area.

In Nova Scotia, a consortium of private and crown corporations will finance a study entitled "Scotia Coal Synfuels Project" (expected completion in late-1982). The study will consider the Cape Breton coal deposits and the feasibility of a 25,000 to 50,000 barrels per day plant which would be capable of providing most of Maritime diesel and aviation fuel requirements. This latter development is interesting in conjunction with the recently announced natural gas discoveries off the coast of Nova Scotia which could provide the needed hydrogen for the proposed coal liquefaction plant.

### 3.6 Hydrogen

Much like propane or the alcohol fuels described above, the use of hydrogen ($H_2$) as a fuel is not new. But the burning of the airship Hindenburg in 1937 is well remembered and, together with the more recent but erroneous link of hydrogen to nuclear warfare, that accident contributed greatly to the widely-held view of hydrogen as being a very dangerous fuel. Many scientists today are prepared to argue, however, that hydrogen is safer than most other fuels.

Although some analysts consider hydrogen a rather exotic fuel which will not gain a great significance before well into the next century, economic conditions prevailing since the early-1970s have led researchers to study the use of hydrogen as a fuel in transportation and elsewhere. In Canada, hydrogen recently received a strong endorsement through recommendations of a special study tabled in Parliament.[32] The all-party report called on the federal government to spend $1 billion during the next five years in order to initiate and speed up the transition over the next fifty years away from dependence on hydrocarbons to a hydrogen-based energy system. While direct use of hydrogen in transportation is unlikely before the year 2000, its indirect use will be extensive since hydrogen is a key component in upgrading of coal, peat or wood.

It is simple to see the potential advantages if hydrogen is used as a transportation fuel. Hydrogen has about two and a half times the energy value by weight of jet fuel, (liquid hydrogen, $LH_2$, has an energy content of about 128 MJ/kg) and can be manufactured from an abundant source - water. Among the chief disadvantages, on the other hand, are the high cost of production, the handling of liquid hydrogen ($LH_2$ must be kept at below -217°C to maintain liquidity), hydrogen's

high evaporation rate, and the low energy content by volume (only about 25 to 30 percent of that of jet fuel).

The main commercial process for manufacturing hydrogen involves its synthesis from natural gas or coal. Lesser amounts are produced from water by electrolysis. In Canada at present, hydrogen is an important feedstock for a number of industries including petroleum refining (used 33 percent of total hydrogen consumed in 1978), chemical industries (52 percent), synthetic fuel production (12 percent) and metallurgy (3 percent).[33] The total Canadian consumption of hydrogen in 1978 was 12.5 x $10^9$ $m^3$, none of which was directly in the transportation sector.

The prevalent method of obtaining hydrogen is through steam reforming of natural gas, or gasification of coal. Owing to large reserves of both of these resources it is not surprising that electrolysis has not been used in Canada on a wide scale in spite of the fact that the Electrolyzer Corporation of Toronto possesses and markets the technology.[34]

Water electrolysis is the only proven technology for the production of hydrogen from non-fossil fuel primary energy sources. It is one of the best known and simplest methods of producing hydrogen from an abundant source, water: electric current passes through water and breaks the water molecule into its two components, oxygen and hydrogen.[35] The net energy input for water electrolysis is greater than that required to produce the electricity which is used in the process. For this reason it is not economic to produce hydrogen by electrolysis unless the marginal cost of electrical power is low enough and there is an adequate power supply. For instance, a case has been made for using off-peak generating capacity or to utilize remote hydro sites from where losses through electric transmission would be too great, but transportation of hydrogen (via rail or pipeline) would be acceptable. Another possibility could be to build a nuclear power plant in a remote area to minimize the nuclear waste disposal problem, produce hydrogen by electrolysis there, and then ship it to markets. The hydrogen, however, would then be more expensive than the electricity.

The second method of producing hydrogen from water is the thermo-chemical process. The water molecule is split by a combination of heat (600 to 1000°C) and catalytic reactions. The development of this technology, however, is not as far advanced as the development of water electrolysis. A major drawback is the very high cost; as well, the process is energy-inefficient and very complex, partly due to the

temperature required for thermolysis, the direct splitting of water by heat alone (thermolysis breaks the water molecule at temperatures between 2500 and 3000°C).

In an early development stage, there exists a third method of producing hydrogen from water via a biological route.[36] The natural process of photosynthesis (the process by which plants power their internal chemical cycles using solar energy) can be simulated using solar energy. A membrane containing particles of chlorophyll is placed in water with catalytic enzymes. Sunlight then 'splits' the water into hydrogen and oxygen through the photosynthesis cycle. Although this process was first successfully tried some seven years ago, its main drawback is its short duration (initially only a few minutes, but now over ten hours). The objective of a viable imitation of the natural photosynthetic system is thus to increase the duration of the process and the rate of hydrogen output.

Opinions differ sharply on hydrogen's potential as a fuel in transportation or space heating. As mentioned above, the recent study tabled in Parliament contained some 65 recommendations, urged the federal government to increase funds for hydrogen research and called for a faster transition to a new energy system based on hydrogen over the next 50 years. A parallel development is under way in Ontario where the provincial government is considering the establishment of an Institute for Hydrogen Systems. The Canadian Hydrogen Energy Society has welcomed this development and one of its founding members has predicted that Canada could move into a hydrogen era as early as 1990.[37] In June, 1981, a $6.2 million program was launched by the government of Ontario to develop and operate the hydrogen-powered buses.

Some recent developments have supported the optimism of hydrogen proponents. For instance, public buses running on hydrogen have been successfully tested in California, Utah and Missouri; the city of Pittsburgh, Pennsylvania is apparently considering the purchase of a fleet of such vehicles. The Daimler-Benz Corporation of West Germany is building hydrogen buses for use in the city of West Berlin; and the Lockheed Corporation of California has proposed a conversion of a fleet of four liquid hydrogen-powered L-1011 Tri Star aircraft for experimental international cargo service in operation by 1987, with Toronto and Montreal among the proposed cities to have hydrogen fuelling facilities (other countries included are the U.S., West Germany, the UK, Japan and Saudi Arabia). It is also possible to have a dual-fuel gasoline/hydrogen vehicle.

Set against the optimists in the development of hydrogen fuel are those who consider hydrogen as a fuel of the more distant future, perhaps beyond the year 2010.[38] Even the federal Minister of Energy called the recommendation of the above mentioned parliamentary report on hydrogen 'futuristic'. The usual arguments put forward against hydrogen fuel are based on the high cost of production, the absence of infrastructure capable of safely handling hydrogen and, perhaps most importantly, on the fact that in Canada we have ample reserves of natural gas which should be used first. From the viewpoint of efficiency, there is little doubt that the presently more economical fuels (natural gas, crude oil and others) should be used first before other, more costly fuels are substituted. The arguments for or against hydrogen fuel perhaps come down to the question of how should future research in hydrogen proceed: how fast and how much resources should be allocated to it in order that a smooth transition can be expected from the current hydrocarbon-based energy system to a new system based on the best alternative.

**Footnotes**

[1]Unlike proposed methanol fuel, chemical grade methanol is a premium grade, nearly 100 percent pure. Methanol fuel is only about 95 percent pure containing impurities including water (about 4.8 percent) and higher alcohols.

[2]Formaldehyde is a component of the glues used in the manufacture of plywood as well as of thermo-setting resins and a myriad of other products. About one half of the world's output of methanol is used for the production of formaldehyde.

[3]That is, one joule of methanol displacing one joule of gasoline. See Ontario, Liquid Fuels in Ontario's Future, Report of the Advisory Group on Synthetic Liquid Fuels of the Ministry of Energy, vol. 1, Toronto, 1978, p. 3-16.

[4]See P. M. Ashton, "Alcohol Fuels in Canada: An Economic and Policy Analysis," EMR/EPAS, Special Studies Division, 1980, p. 34, where a figure 52 percent is used for methanol's energy content. Other sources quote slightly different figures for energy content. They differ due to varying properties of tested gasoline as well as methanol. See for instance J. W. Lincoln, Methanol and the Ways Around the Gas Pump, Charlotte, Vermont: Garden Way Publishing, 1976, p. 38, where the implicit energy content of methanol relative to gasoline is 45.1 percent. Yet another source quotes a value of 49.6 percent. T. O. Wagner et al., "Practicality of Alcohols as Motor Fuel", a paper reprinted in Alcohols as Motor Fuels, Warrendale, Pa.: Society of Automotive Engineers, Inc., 1980, pp. 249-265). Consequently, figure 48.5 percent has been chosen. Some of the confusion as to the energy contents of both methanol and motor gasoline stems from the fact that gasolines vary quite dramatically in energy density when volume based. Generally, on a mass basis, gasoline has an energy content of 47.7 MJ/kg. The specific volume of gasolines vary from 8.1 to 9.0 barrels/tonne. A further confusion is that the energy content can be given in terms of higher (HHV) or lower (LHV) heating value. The LHV is when a substance is burned to give gaseous water, e.g.,

$$CH_3OH_{(g)} + 3/2\ O_2 \rightarrow CO_2 + 2H_2O_{(g)} \quad \Delta H_c = -675.9\ kJ/mole$$

If the water is condensed, the heat of condensation is added to the fuel value thus the HHV is greater;

$$CH_3OH_{(g)} + 3/2\ O_2 \rightarrow CO_2 + 2H_2O_{(l)} \quad \Delta H_c = -763.9\ kJ/mole$$

If methanol has to be a liquid, the values will also be different. If one makes the assumption that gasoline is only composed of iso-octane, then the ratio of energy contents will be 2.12 on a mass basis (HHV) or 2.02 on a mass basis (LHV). On a volume basis, since methanol is more dense than iso-octane, the values are 1.85 (HHV) volume and 1.77 (LHV). Thus the ratio of methanol to iso-octane energy content is 57 percent

(LHV) or 54 percent (HHV). For operational purposes, therefore, a value in the vicinity of 2 volumes of Me OH = 1 volume of gasoline can be used. (The credit for the technical information presented in this footnote is due to one of the official reviewers.)

[5]For a more technical description of the MTG process see, for instance, R. Salmon, M. S. Edwards, and R. M. Wham, "Production of Methanol and Methanol-Related Fuels from Coal," Oak Ridge, Tenn.: Oak Ridge National Laboratories, May 1980; or R. I. Berry, "Gasoline or Olefins from an Alcohol Feed", Chemical Engineering, April 21, 1980, pp. 86-88. Many other sources are available.

[6]See D. F. Othmer, "The efficient Conversion of Valueless Fuels into a Versatile Fuel and Chemical Feedstock," a paper presented at the Annual Meeting of the American Society of Mechanical Engineers, Chicago, November 16-20, 1980, pp. 4-5. Some analysts argue, however, that using methanol for thermal electricity generation in Canada does not represent an efficient use of the energy contained in methanol.

[7]U.S. Department of Energy, The Report of the Alcohol Fuels Policy Review, Washington, D.C., 1979, p. 6. Traditionally, alcohols have been used to increase the octane value of the MOGAS pool when they are in surplus but have been limited in application because emission regulations limit the amount of oxygen that can be added with the fuel.

[8]Ibid.

[9]Adopted from J. B. Simon, A Model for Energy Technology Assessment in Canada, unpublished dissertation, The University of Calgary, Faculty of Environmental Design, 1980, pp. 182-185.

[10]See sources cited in J. B. Simon, Ibid., p. 184.

[11]Ibid.

[12]See A. V. de Carvalho, "Brazil Continues the Rapid Development of Its Alcohol Program", Energy, Winter 1981, pp. 6-7.

[13]See contacts with the car manufacturer cited in Alberta, Energy and Natural Resources, Propane as an Alternative Transportation Fuel in Alberta, prepared by IBI Group, August, 1980, p. 27.

[14]It has been announced that Ford of Canada plans to offer the first factory-produced propane fuelled cars and trucks in North America. Propane-powered Granadas and Cougars are scheduled for 1982, to be followed by heavy and medium-duty trucks with propane option. It is expected that governments and operators of larger commercial fleets will be the first buyers of these vehicles. See The Globe and Mail, May 1, 1981. Propane-powered trucks are also soon to be introduced by International Harvester Company. See The Globe and Mail, February 17, 1981.

[15]Cited in Alberta, Energy, Mines and Resources, Propane as an Alternative Transportation Fuel in Alberta, op. cit., pp. 18-19.

[16]The exact figure estimated by the Canadian Petroleum Association is 2 401 864 million cubic metres. See Oilweek, April 13, 1981, p. 18. The overall Canadian consumption of natural gas, including exports, in 1980 was estimated at 70 041 million cubic metres (2.47 TCF). See Ibid.

[17]R. E. Wyman, "Canadian and Overseas Activities and Research Regarding Methane Powered Vehicles". A paper presented at the 8th Energy Technology Conference in Washington, D.C., March 9-11, 1981.

[18]N. Van Tuyen, "Problems in long-distance LNG Lines". Oil and Gas Journal, December 1, 1980, pp. 107-111.

[19]See for example the recommendations of the House of Commons Special Committee on Alternative Energy and Oil Substitution, Energy Alternatives. Ottawa: the Minister of Supply and Services, 1981, p. 193.

[20]See for instance R. E. Wyman, op. cit.; or The Hon. P. L. McGeer, "A Global Strategy for Introducing Methane as a Motor Vehicle Fuel". A paper presented to the Institute of Gas Technology Symposium, Detroit, June 15, 1981.

[21]R. E. Wyman, op. cit.

[22]Ibid.

[23]In New Zealand, an ambitious plan has been launched by the government to convert 150,000 vehicles to run on natural gas by the end of 1985. At the beginning of 1981, there were 24 CNG refuelling stations along the existing natural gas pipelines and 15 others under construction on the North Island (the two huge gas fields, Maui and Kapuni, are offshore and on the western shore of the North Island, respectively). The New Zealand government is also converting all post office and other vehicles to run on CNG as well as offering cash grants and accelerated tax writeoffs to motorists who convert to the use of CNG. See Ibid.

[24]It should not then be surprising that relative to other industrial countries, Canada has repeatedly been found 'wasting' energy characterized by a high energy/GDP ratio.

[25]The estimate indicates 'mineable' reserves of bituminous, subbituminous and lignite coal. See Canada, Energy, Mines and Resources, "Coal Resources and Reserves of Canada", Report ER 79-9, Ottawa: Minister of Supply and Services, 1980, p. 25. The estimate is deemed 'conservative' by Energy, Mines and Resources (see p. iii).

[26]Many good technical literature sources describing coal liquefaction exist. See for instance I. W. Herring and E. L. Tollefson, "The Economics of Coal Liquefaction in Alberta by Low Temperature Flash Pyrolysis as a Precursor to Thermal Electric Power Generation", presented to the Canadian Gas Processors Association, Calgary, Nov. 23, 1979; or N. Berkowitz, An Introduction to Coal Technology, New York: Academic Press, Inc., 1979; or R. W. Gregory, W. Kasel and J. M. Raisbeck, "Is Coal Liquefaction a Viable Synfuel Option in Alberta?", presented to the 31st Annual Technical Meeting, The Petroleum Society of CIM, Calgary, May 25-29, 1980; D. R. Simbeck, R. L. Dickenson and A. J. Moll, "Coal liquefaction: direct vs. indirect--making a choice," presented at Coal Technology '80, Houston, Texas, November 19, 1980 and reprinted in Oil and Gas Journal, May 4, 1981, pp. 254-268; or F. A. L. Holloway and H. W. Siegel, "Current Status of Coal Liquefaction Technology", presented at the World Energy Conference, Detroit, 1974.

[27]That is, the energy content of the liquid product is 40 to 45 percent of the energy content of the original coal.

[28]This compares with about 0.48 bbl obtained from one tonne of oil sands, plus the handling of 1.8 tonnes of tailing sand. Thus it appears that the mining requirements for coal liquefaction are not as energy extensive as is the case of surface-mined oil sands. See R. W. Gregory et al., op. cit.

[29]Ontario, Ministry of Energy, "Coal in Ontario," Toronto, 1980, p. 23.

[30]See footnote 26 for sources used in the description of these four processes.

[31]See Herring and Tollefson, op. cit.

[32]Energy Alternatives, op. cit.

[33]P. S. Bailey, Assessment of Potential Future Markets for The Production of Hydrogen from Water, a market study prepared for the International Energy Agency, Montreal: Noranda Research Centre, 1980, p. 22.

[34]The Electrolyzer Corp. has so far installed more than 500 electrolyzer units in more than 80 countries. See P. Bailey, op. cit., p. 133.

[35]This method is also very old, with the first patent on water electrolysis awarded in 1888. Today's experience, however, is with small units and improvements will be needed before electrolyzers of a large size (in the thousands of megawatts range) become practical.

[36]See F. Stock, "Hydrogen's Long-term Potential," Petroleum Economist, January 1981, pp. 26 - 28.

[37]Dr. David Scott, Chairman of the University of Toronto's Dept. of Mech. Engineering and a member of the Society.

[38]See for instance the recently completed global analysis of energy issues by the International Institute for Applied System Analysis in Austria. A team of scientists from around the world concluded that hydrogen as a fuel would probably not play a prominent role before 2030. W. Haefele, Program Leader, Energy in a Finite World: Paths to a Sustainable Future. Cambridge, Mass.: Ballinger Pub. Co., 1981, esp. - Chapters 8, 9 and 10.

## Chapter 4

# SUBSTITUTE FUELS: AN ECONOMIC ASSESSMENT

### 4.1 Introduction

This chapter deals with the important topic of economic assessment of the various fuels discussed. It must be stressed at the outset that the assessment is based on available cost information which, although critical, is sometimes not in the form of 'hard data'.

The quality and reliability of economic analysis of this type is to a large degree determined by the quality and reliability of the cost data. The assessment of alternative fuels is complicated by the fact that the fuels discussed, with the exception of propane and methanol, have not thus far been produced on a commercial scale and the available cost data are therefore based only on experimental projects. Once a commercial-scale operation begins, estimates of costs as well as other technical parameters may change. A recent Rand Corporation report[1] suggested that analysts should assume high uncertainty of cost estimates for a commercial plant (around $\pm$ 50%) when data were obtained from a pilot plant scale, with a lower uncertainty (around $\pm$ 20%) assumed once a demonstration plant has been constructed. Generally speaking the most reliable estimates are those based on engineering-economic analysis.

In spite of the difficulties involved, economic assessment of the relative advantages and disadvantages of alternative fuels is essential. With reduction in the dependence of the Canadian economy on crude oil as the major policy objective, the alternative fuels discussed here will play an increasingly important role.

There are three general observations applicable to the economic analysis of alternative fuels which are noteworthy at this time. First, common error is often made when comparing estimates of production costs of alternative fuels with the cost of crude oil (or equivalent). While the cost of crude oil is frequently assumed to rise in the future, at least in nominal or current dollar terms, there is a tendency to assume that the estimated cost of the alternative fuels will be held constant. This usually introduces a bias in favour of the alternative fuels because it distorts the relative costs which are the basis of assessment.

The second observation is that meaningful analysis must compare the various fuels on the same basis. It makes no sense to compare the production cost of, say, methanol with that of gasoline which is produced from subsidized crude oil. Analysis of the question of which alternative fuel is better--at least according to the least-cost criterion--must assure that all the fuels are treated in the same way. The proponents of conservation have argued this point well, suggesting that the same incentives should be offered to those who are prepared to conserve a unit of energy as to those who are willing to produce one.

A final observation relates to the two available strategies for keeping road transportation systems viable in an environment of rising gasoline cost. There are clearly two ways of using less gasoline. One is to improve vehicle fuel efficiency, which is associated with expenditures on new automobile design but which keeps utilizing the very large sunk investment made in the existing fuel distribution network; and the other is to switch to alternative fuels produced from sources other than crude oil, which implies outlays on new facilities, designs and on vehicle conversions. If these two strategies are integrated, the extent to which improved fuel efficiency is cost-effective relative to using an alternative fuel can be demonstrated.[2] These two ways of using less gasoline could, alternatively, be viewed as two investment opportunities which, however, will have quite different distributional effects. While the cost of improved vehicle fuel efficiency will be reflected in the higher prices new car and truck buyers will have to pay, the cost of alternative fuels will to some extent fall on all taxpayers if various incentives are introduced to make new fuel development and production more attractive. The costs of alternative liquid fuels are compared in section 4.8 below, where they are also compared to the marginal cost of producing more fuel-efficient vehicles.

Appendix A specifies the general assumptions used in estimating the costs of production of the fuels discussed. Unless stated otherwise, all costs are expressed in 1981 Canadian dollars.

### 4.2 Methanol

Because the production of most alternative liquid fuels (and synthetic fuels generally) is capital intensive, the cost of the final product is extremely sensitive to the assumed rates of return, to the ratio of debt to equity capital employed and to the rate of interest

paid on borrowed capital. Very different results can be obtained with changes of these parameters.

In Canada, resources from which methanol could be produced on a commercial scale include natural gas, coal, lignite, peat, municipal solid waste, animal refuse and biomass (wood). A number of options exist both in the sources of feedstock and the conversion technology. Depending on the cost of feedstock and location of the plant, the cost of methanol would fall somewhere between $157 and $409 per cubic metre ($25 and $65 per barrel) of crude oil displaced, although some estimates are even higher. This does not mean, however, that methanol as a fuel then becomes price-competitive with fuels derived from crude oil in transportation, household or industrial applications. Since a methanol distribution system is not in place, motor vehicles and other end-uses require modifications. Also, because methanol has a lower calorific value than gasoline, a discount for methanol relative to the price of conventional fuels would be required.

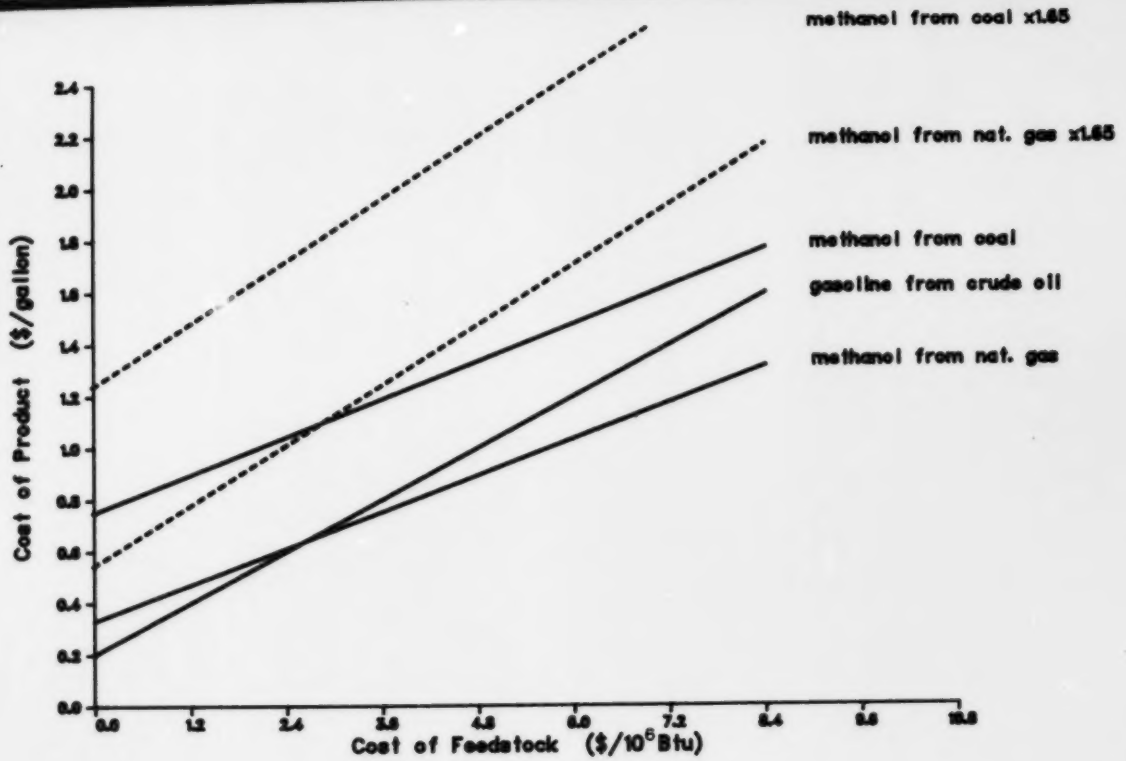
The least costly feedstocks for methanol production are low-priced natural gas and coal. A litre of methanol produced from coal could cost some 18 cents if produced in western Canada (80¢/gallon). In Ontario, with peat used as the source, the cost would be slightly higher, in the range of 18 to 18.3¢/litre (80 to 83¢/gallon). Produced from wood wastes in B.C., Ontario or Quebec, the price per litre would probably be about 18.7 cents (85¢/gallon).[3] In comparison, if natural gas were available at the domestic price of 9.23¢/$m^3$ ($2.60 per Mcf), then the production cost would be considerably cheaper, around 13.5 ¢/litre (61¢/gallon). If the natural gas feedstock were priced at the export price of 20.9¢/$m^3$ ($5.80 per Mcf), methanol produced in Alberta from natural gas would cost 22¢/litre (just under $1.00/gallon). All these estimates are production cost estimates excluding taxes. The relationships between the cost of methanol and the price of feedstocks are specified in Table 4.1 and shown graphically in Figure 4.1.

Figure 4.1 also contains two broken lines which show more precisely the cost of methanol as a transportation fuel when it is recognized that, relative to gasoline, methanol contains less energy per volume. It has been mentioned above (see footnote 4, Chapter 3) that methanol burns some 25 percent more efficiently than gasoline but that it has only about 48.5 percent of the energy content. When these two properties are combined, methanol would have to be priced roughly

TABLE 4.1

METHANOL-GASOLINE COST RELATIONSHIPS

| FEEDSTOCK COST $/1,055 MJ (1) | FEEDSTOCK COST EQUIVALENT (2) | Methanol From Coal (¢/litre) (3) | Methanol from Natural Gas (¢/litre) (4) | Gasoline from Crude Oil (¢/litre) (5) | Column 3 x 1.65 (¢/litre) (6) | Column 4 x 1.65 (¢/litre) (7) |
|---|---|---|---|---|---|---|
| 0.00 | 0 | 16.5 | 7.3 | 4.4 | 27.2 | 12.0 |
| 0.40 | $ 7.87/tonne | 17.6 | 8.3 | 5.9 | 29.0 | 13.7 |
| 0.50 | $ 9.84/tonne | 17.8 | 8.6 | 6.2 | 29.4 | 14.1 |
| 1.00 | $ 19.69/tonne | 19.2 | 9.9 | 8.1 | 31.7 | 16.3 |
| 1.20 | $ 44.02/$m^3$ | 19.7 | 10.4 | 8.8 | 32.5 | 17.1 |
| 2.00 | 7.10¢/$m^3$ | 21.9 | 12.4 | 11.7 | 36.1 | 20.5 |
| 2.40 | 8.52¢/$m^3$ | 22.9 | 13.5 | 13.2 | 37.8 | 22.2 |
| 3.00 | 10.65¢/$m^3$ | 24.5 | 15.0 | 15.4 | 40.5 | 24.8 |
| 3.60 | $132.07/$m^3$ | 26.2 | 16.6 | 17.6 | 43.2 | 27.3 |
| 4.80 | $176.09/$m^3$ | 29.4 | 19.7 | 22.0 | 48.5 | 32.5 |
| 5.20 | 18.46¢/$m^3$ | 30.4 | 20.7 | 23.5 | 50.2 | 34.2 |
| 6.00 | $220.12/$m^3$ | 32.6 | 22.8 | 26.4 | 53.8 | 37.6 |
| 7.20 | $264.14/$m^3$ | 35.8 | 25.9 | 30.8 | 59.1 | 42.7 |
| 8.40 | $308.16/$m^3$ | 39.0 | 29.0 | 35.2 | 64.4 | 47.8 |




Source: See Appendix B and C

FIGURE 4.1: METHANOL-GASOLINE COST RELATIONSHIPS

at no more than 60 percent[4] of the price of gasoline to be price-competitive since it takes about 1.65 litres of methanol to carry a vehicle an equal distance as one litre of gasoline.

To arrive at a cost estimate of methanol production which would be comparable with the current price of gasoline, we may conveniently begin with the present market price of commercially produced chemical methanol. Chemical methanol, however, may turn out to be purer (higher quality) than will be required for methanol fuel and thus a slight upward bias may be introduced in using this approach. Nevertheless, chemical methanol is produced commercially and that makes the existing market price (which includes taxes, but no road tax) a good starting point for a cost comparison.

The market selling price of regular gasoline (which also includes taxes and, with the exception of Alberta, also a road tax) was on average 30¢/litre in Edmonton and Calgary (39¢/litre in Toronto) in the summer of 1981, compared with the price of 24¢/litre of methanol.[5] Priced at 60 percent of the price of gasoline, methanol would have been price-comparable with gasoline if priced at 39.6¢/litre. That would have been almost equal to the price of gasoline in eastern Canada. This comparison does not include allowances for the cost of engine modifications and for distribution required in the case of methanol. General Motors and Volkswagen have both estimated the modification costs to be between $300 and $500 (1980 $) per vehicle.[6] Assuming a cost of $400 over the lifetime of a vehicle, this translates into a penalty of about 1.2¢/litre of methanol.[7] Estimates of the cost of distribution of alcohol fuels are difficult to obtain but one available source has put it at about 3.5¢/litre.[8]

Adding these two cost elements to a base price of 39.6¢/litre of methanol, a final price-comparable estimate for methanol of 44.3¢/litre is obtained. These cost estimates are summarized in Table 4.2. It can be seen that the estimates shown there put methanol within reach of the price of gasoline in the Toronto market, but still too expensive relative to gasoline in western Canada.

The comparison is, of course, based on current conditions, with Canadian motorists being sheltered from the full effect of the international price of oil. Any future developments will be determined by changes in the relative prices of both of these fuels. If the price of gasoline (crude oil) rises faster than that of methanol, the latter can be expected to become a viable alternative transportation fuel, at least in eastern Canada. Changes included in the recent energy

TABLE 4.2

THE COST OF METHANOL[a] VERSUS REGULAR GASOLINE

| | Cents per Litre |
|---|---|
| Methanol Cost: | |
| Current selling price | 24.0 |
| Penalty for lower Btu content relative to gasoline | 15.6 |
| Allowance for engine modifications | 1.2 |
| Distribution cost | 3.5 |
| Total estimated cost | 44.3 |
| Gasoline Cost: | |
| Calgary | 30.0 (55)[b] |
| Toronto | 39.0 (68)[b] |

[a]Based on the market price of methanol and gasoline in the summer of 1981.

[b]An approximate cost if based on the full international price of crude oil ($251.60/m$^3$ or $40.00/bbl), assuming all other relationships unchanged.

agreement between the federal government and Alberta suggest that, for the next three years at least, prices of gasoline will rise at a rate significantly above the anticipated rate of inflation.[9] If one assumes that the cost of methanol will rise at the rate of inflation, then methanol will clearly become a competitive transportation fuel within several years.

The above estimate of the cost of methanol (44.3¢/litre) is consistent with other available estimates. Table 4.3 summarizes the results of five other recent studies, two dealing with methanol production in the United States[10] and three in Canada. The results provided by the Mellon Institute study show clearly the dramatic differences which can be obtained when the method of financing is altered. The relationship between the rate of return on equity and the selling price of methanol is shown in detail in Figure 4.2.

An attractive avenue for further research in the area of biomass and peat conversion into liquid transportation fuels is the utilization of a liquid product known as 'proto oil'. Both biomass and peat contain between 50 and 95 percent moisture, most of which must be removed when methanol is produced. A considerable amount of energy could be saved if the drying step were removed. This is what occurs in proto oil production. At least 30 percent greater energy efficiency relative to methanol production can be achieved. Only experimental production of proto oil, however, has thus far taken place and the economics of proto oil are still uncertain. Although proto oil is not yet usable as a transportation fuel, it has been suggested that it could be used as a substitute for bunker oil.[11]

It is clear that methanol, either as an octane supplement, a blend with gasoline or neat, will find its way into the market for transportation fuel during the 1980s. The remaining question is the extent to which it will penetrate that market. This will depend on the actual cost of production once commercial-scale operations begin.

### 4.3 Ethanol

It was noted earlier that the production costs of ethanol are much higher than those of methanol. The biggest problem is the cost of feedstock. This is because biomass resources suitable for ethanol production (grains, sugar beets, etc.) do not have high energy density, are dispersed in their occurrence, and many command considerable value

TABLE 4.3

METHANOL PRODUCTION COSTS

| | | Estimated Cost In Terms of Oil Equivalent (1981 ¢/L) |
|---|---|---|
| (i) Gov't of Ontario Policy and Strategy Paper[a] | | |
| feedstock: | nat. gas (1980 $ 3.52/Mcf) | 40.7 - 43.4 |
| | western coal (1980 $ 1.81/GJ) | 30.4 - 45.5 |
| | Ontario lignite (1980 $ 12/tonne) | 37.2 - 49.6 |
| | Ontario wood (1980 $ 45/ODt) | 51.0 - 53.1 |
| (ii) NRC[b] | | |
| feedstock: | wood or peat (1980 $ 30/ODt) | 28.7 - 34.7 |
| (iii) BBC Engineering[c] | | |
| feedstock: | wood | 32.3 |
| (iv) Wagner et al[d] | | |
| feedstock: | wastes (plant is paid 1981 $ 7.40/ton) | 38.9 |
| | lignite (1981 $ 8.90/ton) | 29.4 |
| (v) Mellon Institute[e] | | |
| feedstock: | coal, no debt, method of financing: 22% ROR; coal in all cases at 1980 U.S. $ 23.10/ton; | 71.8 |
| | coal, no debt, 15% ROR | 58.1 |
| | coal, 50% debt, 15% ROR, 12% interest on debt | 46.0 |

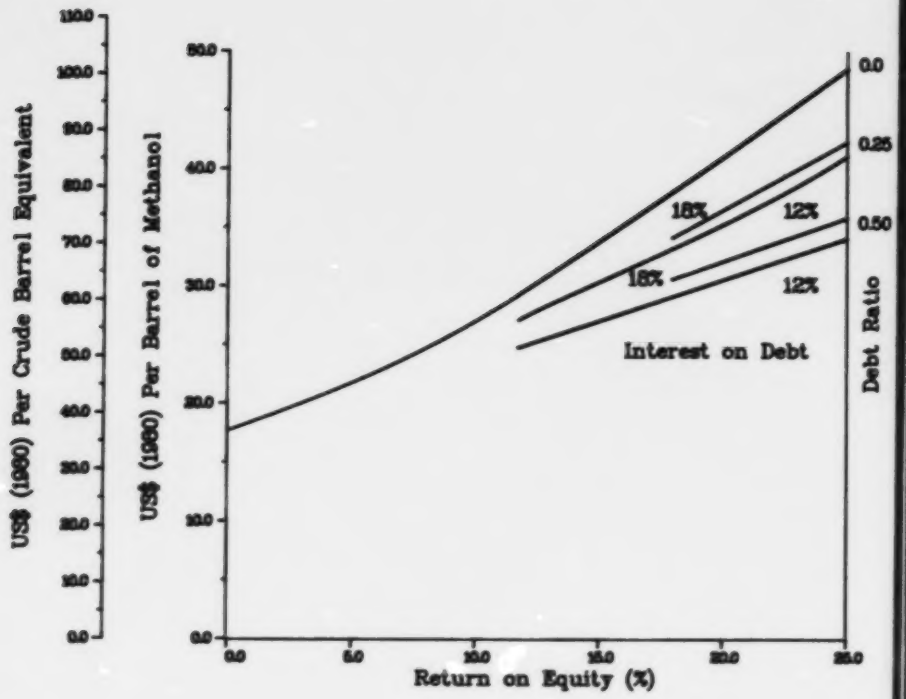
[a]Ontario, Ministry of Energy, "Alternative Transportation Fuels for Ontario," Toronto, February 1981.

[b]R. Overend, N.R.C., "Notes on Synthetic Liquid Fuels in Canada," Ottawa, March 1980. Production cost estimates found in this paper were translated into oil equivalency using data from Table 4.2 above.

[c]J. W. Black, BBC Engineering, "The Potential for Energy Transfer from Wood Based Methanol Plant to a Thermomechanical Plant: Facility Review," Markham, Ontario, January 1980. This study assumes significant savings in terms of the amount of wood used. While other studies ascertained that 2.3 dry tons of wood would yield one ton of methanol, BBC Engineering presented an engineering design based on 1.77 tons/ton of methanol.

[d]T. O. Wagner et al, op. cit.

[e]R. H. Shackson and H. J. Leach, op. cit., p. 69.




Assumes: –Methanol production from coal
–103,750 B/D plant capacity
–coal gasification technology
–US location

Source: Bechtel Corp., quoted in R.H. Shackson, op. cit., p. 88.

FIGURE 4.2: MINIMUM PRICE REQUIRED FOR METHANOL PRODUCTION

in non-energy uses such as food production or livestock feed. Questions regarding land use and sharply rising prices of feedstock produced on a wide scale to support commercial production of ethanol are often discussed when the issue of ethanol use as a fuel is raised.

On one hand, it is argued that, as a result of large-scale ethanol production, food prices will rise substantially; but on the other, it has been claimed that the so-called 'food-fuel' conflict is more myth than reality.[12] The economic proof that this conflict is real, however, is quite simple. If an agricultural product (a crop) commands a higher market value as an energy feedstock than as food, no one will want to grow food and vice versa. While there may be ways of getting around this problem, the potential for conflict is real--even at the simple level of driving up food prices. The 'food-fuel' issue is also highly emotional. Before beginning to argue about the ethics of converting food to fuel, it may be useful to realize that our society is engaged in another generally unopposed but grossly energy inefficient process which is that of feeding corn and barley to cows to produce beef. But again, the market supports this process on the basis of consumers' tastes and preferences. It should be made clear though, that if agricultural products are used to manufacture ethanol, the price of the latter will be subject to the usual fluctuations of agricultural output and prices.

As a supplement to automotive fuel, gasohol (10 percent ethanol and 90 percent regular gasoline) could be useful in reducing Canadian dependence on foreign supplies of crude oil, especially if produced from spoiled or surplus crops grown on marginal land. The House of Commons Committee on Alternative Energy and Oil Substitution has concluded that there are not sufficient ethanol feedstock resources (not counting cellulose) to provide enough ethanol to meet the needs of the transportation sector. The Committee recommended, however, that the federal government ensure (through amendments to the Excise Act) that potential excess output of ethanol may be sold by individual producers to retail suppliers of alcohol fuel or gasohol.[13]

Ethanol is considered here only as a supplement to gasoline supply. Hence engine modification costs are not included in the estimates since it is assumed that ethanol is used in the form of gasohol. It has been mentioned that ethanol contains less energy per litre than gasoline, but that ethanol raises the octane rating of gasoline (gasohol). Since laboratory estimates of both of these specific properties differ among available sources, it is assumed that Canadian motorists are indifferent between the use of regular gasoline

and gasohol if they command an equal price, or that they will prefer the cheaper of the two in the case that their prices differ.[14] In other words, it will be assumed that gasoline and gasohol are substitutes.

As in the case of methanol, the cost of ethanol production is dependent on the cost of feedstocks. But, in contrast with methanol production, capital charges are not the single major element of cost; the cost of feedstock is equally as significant as the construction cost. In Canada, the feedstocks from which ethanol could be produced commercially in the near future include wood biomass and certain agricultural products. Feed barley is the feedstock being used at the first commercial-scale Canadian ethanol production plant of Mohawk Oil Co. Ltd. in Manitoba.

Depending on the type and cost of feedstock and on other assumptions, estimates of the production cost of ethanol vary from a low of about 39¢/litre to a high of 95¢/litre. Table 4.4 summarizes several available estimates for both Canada and the United States and Appendix B shows a more detailed expenditure schedule for a sample ethanol-producing plant. The difference to be noticed in Appendix B is in the construction cost which is significantly lower in the case of the ethanol plant in spite of much lower output. As for Table 4.4, the estimates predictably differ depending on the feedstock or the assumed profitability of the operation. It should be noted that the lowest estimate (Wayman et al.) does not assume any tax and is therefore biased downward, unless one assumes government tax incentives.

Estimated rates of return of an ethanol plant are shown in Figure 4.3 where the rate of return on investment is shown in relation to the selling price of ethanol, the size of the debt/equity ratio and the interest on debt. Figure 4.4 shows the sensitivity of the required selling price of ethanol to the costs of two types of feedstock.[15]

Since there currently is no established market for ethanol (gasohol) in Canada, it is difficult to draw hard conclusions from the production cost estimates in Table 4.4. The estimates can, however, be compared with the present market price of gasoline for which gasohol is assumed to be a substitute. By fall of 1981, it was only known that gasohol would be marketed at a price 'competitive' with that of gasoline.[16] Earlier analysis revealed that Mohawk's operation at Minnedosa would be viable only because of a tax exemption granted by the Manitoba government. Gasohol (ethanol) has been exempted from the provincial gasoline tax of about four cents a litre. With a 10/90

TABLE 4.4

ETHANOL PRODUCTION COSTS

| | | Estimated Cost (1981 ¢/L) |
|---|---|---|
| (i) Wayman et al.[a] | | |
| feedstock: | aspen wood (1978 $25/Dt, no tax assumed | 38.3 - 40.7 |
| (ii) Mohawk Oil[b] | | |
| feedstock: | wheat | 57.9 - 60.3 |
| (iii) Government of Ontario Policy and Strategy Paper[c] | | |
| feedstock: | Ontario grain corn (1980 $3.00/bushel) | 61.4 - 69.6 |
| (iv) Wagner et al.[d] | | |
| feedstock: | corn (a mix of fresh and distressed at a combined cost of 1978 U.S. $ 2.30/bushel) | 56.9 |
| (v) U.S. Dept. of Energy[e] | | |
| feedstock: | wheat (1978 U.S. $3.15/bushel) | 56.5 |
| | sugar cane (1978 U.S. $65/ton) | 90.2 |
| | wheat straw (1978 U.S. $25/ton) | 94.5 |
| (vi) Mellon Institute[f] | | |
| feedstock: | corn, no debt method of financing 22% ROR, corn in all three cases at 1980 U.S. $ 2.80/bushel | 89.5 |
| | corn, no debt, 15% ROR | 79.0 |
| | corn, 50% debt, 15% ROR, 12% interest on debt | 71.8 |

[a]M. Wayman, J. Lora and E. Gulbinas, "Material and Energy Balances in the Production of Ethanol from Wood," reprinted in Chemistry for Energy, ACS Symposium Series 90, 1979 (a paper presented at a symposium sponsored by the Chemical Institute of Canada at the Annual Conference in Winnipeg, June 1978).

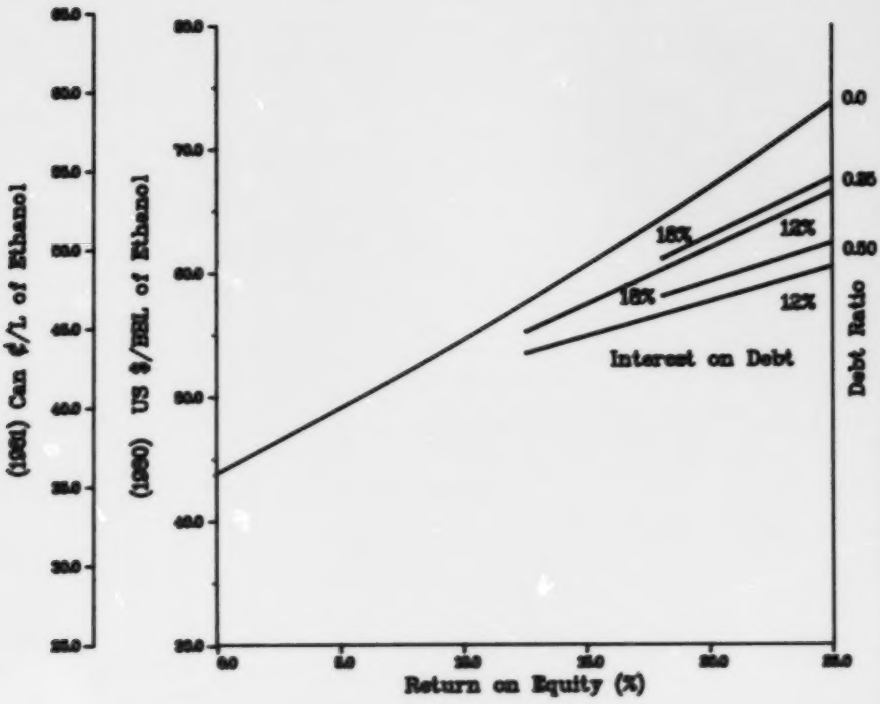
[b]A. Mayer, Mohawk's research consultant, quoted in The Calgary Herald, August 21, 1980, and personal communication.

[c]Ontario, Ministry of Energy, "Alternative Transportation Fuels for Ontario", op. cit., p. 13.

[d]T. O. Wagner et al, op. cit.

[e]U.S., DOE, The report of the Alcohol Fuels Policy Review, Washington, D. C., 1979, p. 74.

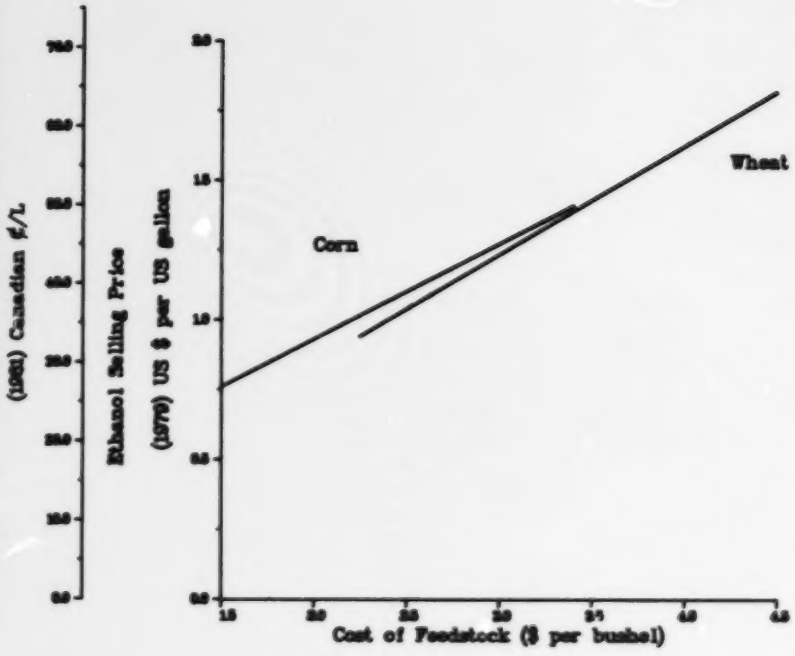
[f]R. N. Shackson and N. J. Leach, op. cit., p. 69.




Assumes: -Ethanol production from corn
-3,068 BBLS/D plant capacity
-US location

Source: Bechtel Corp., quoted in R.H. Shackson, op. cit., p. 90.

FIGURE 4.3: MINIMUM PRICE REQUIRED FOR ETHANOL PRODUCTION




Assumes: -100% equity financing
-15% DCF
-20 yrs. operating life
-US location

Source: US Dept. of Energy, The Report of the Alcohol Fuels, op. cit., p. 93.

FIGURE 4.4: SENSITIVITY OF ETHANOL SELLING PRICE TO THE COST OF FEEDSTOCK

percent ethanol/gasoline mixture, this exemption works out to a 40¢/litre subsidy for each litre of alcohol produced (and mixed with gasoline to obtain gasohol). While the estimates in Table 4.4 suggest that, even as a gasoline supplement, ethanol would presently be greatly uneconomic, a tax exemption like the one in effect in Manitoba would change that conclusion. On an equal basis, however, ethanol production appears much more costly relative to either gasoline or some of the other alternative fuels considered here.

### 4.4 Propane

With the price of gasoline rising, the competitiveness of propane relative to gasoline has recently been improving. It is a stated objective of the federal government (viz. NEP) to increase the use of propane. The rising price of gasoline could accelerate the process, especially in the case of centrally fuelled large fleet operations.

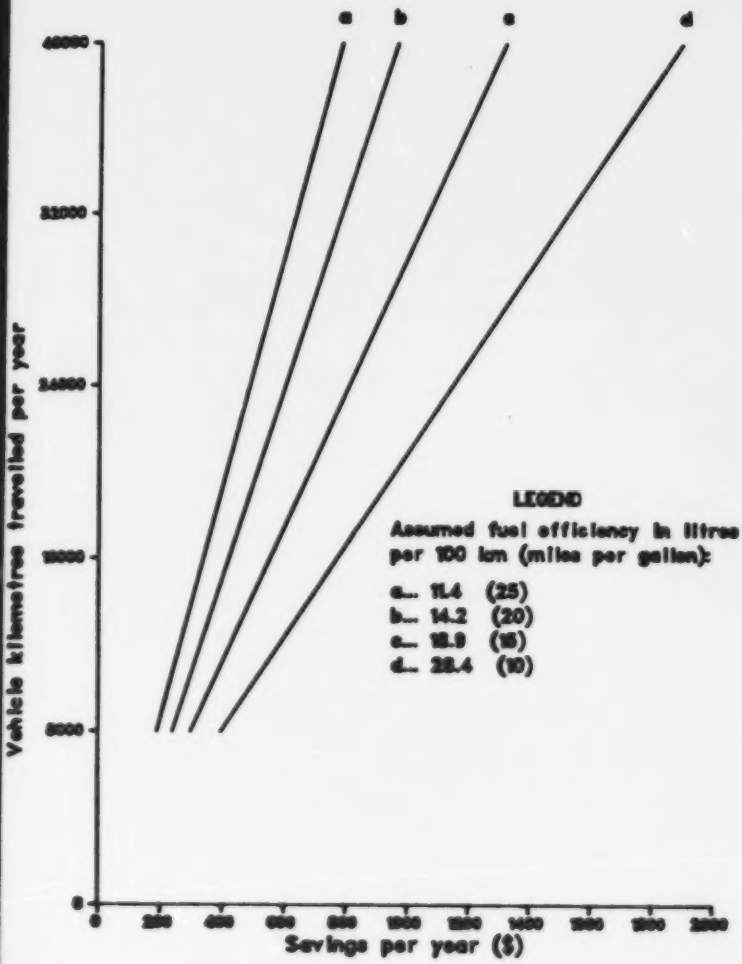
Since the mileage is about equal for propane as for gasoline[17] it can be assumed that the only extra cost associated with the use of propane is the cost of engine conversion.[18] However, certain savings may be realized with propane in terms of reduced engine maintenance costs. Estimated propane conversion costs for various types of vehicles are listed in Table 4.5. Given this information and some additional assumptions, the current market price of propane can be compared to that of gasoline to arrive at an estimated pay-off period required for the cost of propane conversion. This procedure is shown in Table 4.6 and illustrated in Figure 4.5.

TABLE 4.5

ESTIMATED COSTS OF VEHICLE PROPANE CONVERSION (CALGARY)

| Type of Vehicle | Cost per Vehicle in $ (parts and labour) |
|---|---|
| Small car (e.g. Honda Civic) | 900 - 1,000 |
| Taxi (full-size North American car) | 1,500 - 1,700 |
| Light truck | 1,400 |
| Heavy truck (3 - 5 tons) | 1,800 |
| Van | 1,300 - 1,400 |

SOURCE: Market survey of three propane conversion shops in Calgary, Summer, 1981.




Source: Based on Table 4.8

FIGURE 4.5: VARIATIONS OF SAVINGS ON PROPANE CONVERSION

It can be seen that, depending on the type of a vehicle and the miles driven, the original cost of propane conversion could be recovered in a relatively short time period ranging from a low of around one year up to about three years.[19] The annual savings depend heavily not only on the miles travelled and the achieved mileage of a car, but also on the difference in price between gasoline and propane. That difference has, in fact, been growing in recent months. Between March and September of 1981, the price of gasoline (in Calgary) increased by 39 percent, whereas the price of propane rose only by 6.7 percent. The spread between the two prices thus increased by 78 percent (from 9¢/litre to 16¢/litre), making propane conversions more attractive.

It should also be noted that the calculations in Table 4.6 do not include the taxable $400 grant for each commercial vehicle converted to propane offered through the National Energy Program. Excluded are also other tax incentives such as that in effect in Ontario where, beginning in 1980, the provincial government exempted all exclusively propane-powered vehicles from the gasoline road tax (then 4.6¢/litre or 21¢/gallon) and the 7 percent retail sales tax (including the conversion kits). Including these tax incentives shortens the pay-off period still further (depending on location and the tax position of the vehicle operator). Thus it is conceivable that, in the case of high-travelled vehicles with poor fuel efficiency and a short radius of action (taxis, delivery trucks but also vans and ordinary passenger cars), conversion to the use of propane could pay for itself in six months.

For those who are considering the conversion the important questions are: (i) at what rate will the cost of conversion rise in the future, or will it perhaps even fall if conversion kits become available on a wide scale?; and (ii) what will happen to the difference between the price of gasoline and propane?

It could be assumed that the conversion cost will rise at the rate of industry inflation. The second question is more difficult to address since the future price of propane, not gasoline, is uncertain. As a result of the recent agreement between the governments in Ottawa and in Alberta and British Columbia, the future price of gasoline has been to a large extent determined until the end of 1986.

If the future price of propane increases in response to the rising price of natural gas, then the spread between the prices of propane and gasoline can be expected to increase, making conversions to propane even more attractive than shown in Figure 4.5. If, however,

TABLE 4.6

THE VIABILITY OF PROPANE VEHICLE CONVERSION

(i) Assumptions:
- Vehicle A travels 16,000 kilometres per year
- Vehicle B travels 32,000 kilometres per year
- Fuel efficiency is equal between gasoline and propane on volume basis
- Both vehicles need 14.2 litres of gasoline to travel 100 kilometres
- Annual cost for oil changes and propane engine maintenance is one half of that of a gasoline-powered engine (assumed to be $100)

(ii) Current Fuel Costs[a] (Calgary, September, 1981)
- regular gasoline 32¢/L
- propane 16¢/L
- propane advantage 16¢/L ($.727/gallon)

(iii) Annual Savings Due to Conversion
- Vehicle A: (16,000 x .142) x .16 = $363.50/year
- Vehicle B: (32,000 x .142) x .16 = $727.00/year
- Maintenance savings $50.00/year

(iv) Total Savings
- Vehicle A: $413.50/year
- Vehicle B: $777.00/year

[a]A comparison of propane and gasoline prices in Toronto, for instance, would have to take into consideration the gasoline road tax levied there which has, however, been repealed for all alternative fuels including propane. There is no road tax on either gasoline or propane in Alberta.

the propane price also increases in response to the (more rapidly) rising price of crude oil, the price spread may stay constant or even diminish, rendering conversions somewhat less attractive.[20] The price of propane could also rise simply as a result of market conditions where demand, following initial upsurge of propane conversions, outstrips supply.

On the basis of currently available information and less than perfect foresight, propane conversions are now economically viable, especially for those who drive long distances with gasoline-powered vehicles having poor mileage ratings. Given the possibility of increasing propane production and the number of retail outlets, it can be expected that propane will become a significant alternative transportation fuel in the near future.

### 4.5 Compressed Natural Gas

The case of CNG is interesting for the reason that it has apparently been overlooked by the National Energy Program as a viable near-term alternative transportation fuel similar to propane. This could be partly due to a lack of previous commercial use of CNG in Canada, which thus far has not been on the same level as that of propane. Use of propane in small fleets in Canada dates back more than ten years. CNG, however, has been used in other parts of the world (notably in Italy) for much more than a decade and hence a good deal of experience exists. In contrast, by summer of 1981, there were no established comprehensive standards governing the use, transportation and storage of CNG in Canada which could, in part, be the reason for the differential treatment with respect to tax breaks of CNG and propane in the National Energy Program. Current activity in CNG research and utilization has increased, however, and there are strong indications that CNG will play an important role as a near-term alternative transportation fuel. In January, 1982 a taxable grant of $600 was introduced for those motorists who switch from gasoline to CNG to partly offset the conversion cost. In principle, using natural gas directly in the form of CNG makes better energy sense than converting it to other forms of energy, like methanol or gasoline, since the conversion processes involving those fuels necessarily consume a significant amount of the energy contained in the initial resource. In the case of CNG, a smaller energy loss will be due to the work needed to compress the gas into the vehicle tank. This loss will be relatively smaller if the natural gas is taken for compression from the (higher pressure) distribution system than if it is drawn from the (lower pressure) system at the consumer's house.

The economics of using CNG are not dissimilar to the case of propane, although the conversion cost seems slightly higher. Table 4.7 shows a sample calculation of possible fuel bill savings for a CNG conversion. The calculation is performed on the basis of combustion energy content of gasoline and CNG, assuming that an equal amount of energy in CNG will replace the energy contained in gasoline. It is also assumed that a $50 saving per year will be realized due to a lower maintenance cost when using CNG. No explicit assumptions have been made regarding the amortization and operating cost of the compressor. This, however, may be partly (or fully) offset by assuming a higher price for natural gas feedstock (9.23¢/$m^3$ or $2.60/Mcf) than the actual price currently paid. With these and other specified assumptions in place, annual fuel savings come to $584 and $1,385 for converted vehicles travelling 16,000 and 40,000 kilometres per year, respectively. As in the case of propane, the taxable grant ($600) now available for those who switch to CNG is not included in the calculations, but the existence of the grant improves the economic viability of converting still further.

These figures can be compared with the cost of conversion. It has been estimated that to convert a vehicle to CNG would cost somewhere between $1,600 and $2,000.[21] It is clear that, depending on the cost of money assumed in a detailed calculation of the length of the pay-off period, CNG conversion, like propane conversion, is now economically viable. It will clearly appeal more to fleet operators or those with less energy efficient vehicles travelling long distances than to private car owners but, again, much will depend on future relative prices of natural gas, gasoline and the escalation of the conversion cost.[22]

Since the future price of natural gas has to a large extent been determined through the recent energy agreement, perhaps less uncertainty surrounds its development than that of the price of propane (although propane is predominantly derived from natural gas). One important question is: "At what price will the CNG retail outlets be able to purchase natural gas?" In Table 4.7 it was assumed that the price is 9.23¢/$m^3$ ($2.60 per Mcf), although natural gas as a petrochemical feedstock is sold in Alberta for around 6.74¢/$m^3$ ($1.90 per Mcf). In eastern Canada, the city-gate price of natural gas was 10.83¢/$m^3$ ($3.05 per Mcf) in mid-year 1981. In B.C., the maximum field price has recently risen to 5.93¢/$m^3$ ($1.67 per Mcf) and, for comparison, the export price of Canadian natural gas is 20.59¢/$m^3$ ($5.80 per Mcf).

TABLE 4.7

THE VIABILITY OF CNG CONVERSION

(i) Assumptions:
- Vehicle A travels 16,000 kilometres per year
- Vehicle B travels 40,000 kilometres per year
- Both vehicles need 14.2 litres of gasoline to travel 100 kilometres
- Combustion energy content of 1 litre of gasoline = 33.245 MJ (143,055 Btu per gallon), 1 cubic metre of natural gas = 35.576 MJ (950 Btu per cubic foot) and thus 1 litre of gasoline = .9345 cubic metres of natural gas
- cost of gasoline = 32¢/L ($1.46/gallon)
- Maintenance cost savings when using CNG is $50/year
- cost of natural gas = 9.23¢/$m^3$ ($2.60/Mcf)
- the basis for comparison is the combusion energy content

(ii) Current Gasoline Cost (Calgary, September, 1981)
- Vehicle A: (16,000 x .142) x .32 = $727.00/year
- Vehicle B: (40,000 x .142) x .32 = $1,818.00/year

(iii) Equivalent Cost of CNG:
- Vehicle A: 2,272 x .9345 = 2,123 $m^3$
  = 2,123 $m^3$ x .0923 = $195.95/year
- Vehicle B: 5,680 x .9345 = 5,308 $m^3$
  = 5,308 $m^3$ x .0923 = $489.93/year

(iv) Total Savings
- Vehicle A: 727.00 - 195.95 + 50.00 = $581.05/year
- Vehicle B: 1,818.00 - 489.93 + 50.00 = $1,378.07/year

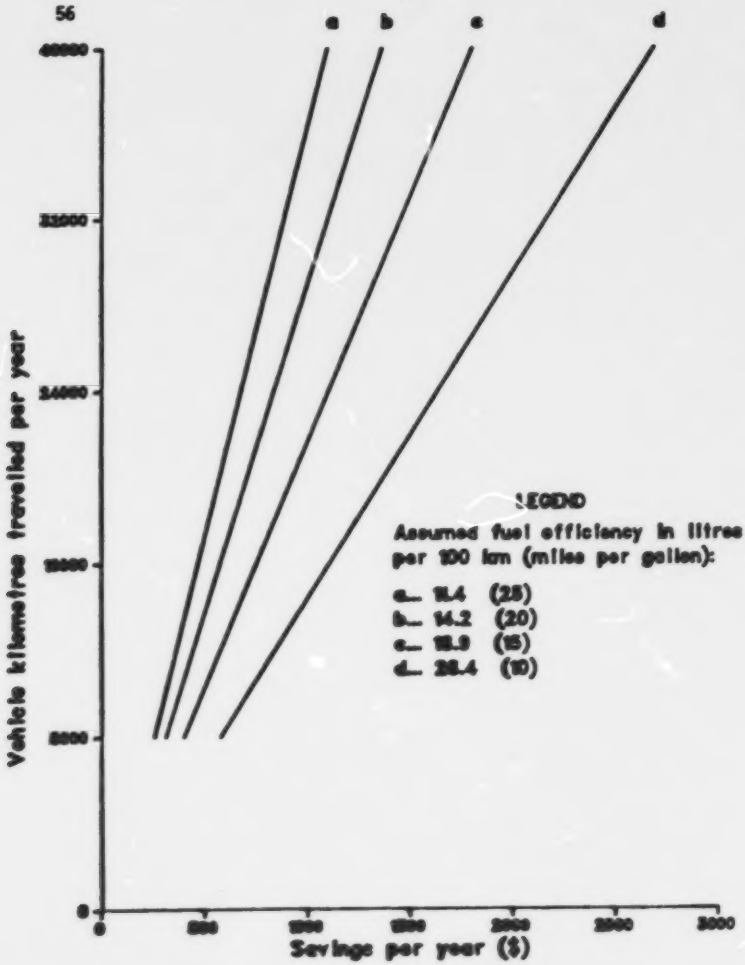
The price of natural gas is therefore critical for the assessment of economic viability of CNG conversion. Very different results for annual fuel savings and hence the length of the pay-off period can be obtained with different natural gas price assumptions. Figure 4.6 shows the variations of fuel savings according to miles driven per year and mileage achieved.

Although a discussion of the economics of CNG and propane conversions presumes a competition between the two fuels, it is more appropriate to see them as two viable near-term alternative ways of moving off oil in the transportation sector. The two fuels can exist side by side, much like gasoline and diesel exist now. Both CNG and propane are in fact alternative fuels which are ready to be used on a much wider scale now although their use will initially appeal more to large users. Out of the several alternatives discussed here, these two fuels are also the closest to having a distribution system in place.[23]

**4.6 Liquefied Coal**

Among the alternative fuels, indirect coal liquefaction has frequently been described as promising and this method is in fact currently employed on a commercial basis in South Africa. Since the technology is well established, a coal liquefaction plant could be built either in the eastern consuming provinces or in western Canada. But to minimize coal transportation cost, a western location would seem preferable.

An economic assessment of the production of liquids from coal, however, tends to favor other fuels. Particularly the oil sands--the 'natural' alternative to coal in the production of liquid fuels--seem more economical.[24] This is primarily because the chemical properties of oil sands (bitumen) are closer to the final refined products than those of coal. It is also cheaper to extract oil sands than coal on an equal scale. Recent technical and economic sources contain a number of cost estimates, some of which suggest that liquid fuels from coal may be nearly competitive with oil sands. One Canadian estimate put the construction cost of a coal liquefying plant producing 22,258 $m^3$ (140,00 barrels) a day (excluding the cost of the coal mine) at (1980) $4.7 billion but the annual operating cost was valued at about (1980) $800 million which is at least twice the estimated operating cost for an oil sands plant of the same capacity.[25] The only way to verify the estimates, however, would be to build a commercial-scale plant.




Note: Assumes natural gas at 9.23¢ per cubic metre ($2.60/Mcf).

Source: Based on Table 4.7

FIGURE 4.6: VARIATIONS OF SAVINGS ON CNG CONVERSION

Table 4.8 lists some recent cost estimates for the production of liquids from coal for both Canadian and U.S. locations.[26] Strict across-the-board comparison of the cost figures in Table 4.8 must again be made only with caution since the underlying assumptions differ between sources.[27] It can be observed in Table 4.8 that all estimates originating in Canada [(i) to (v)] are within the range of $159 to $275 per $m^3$ ($25 to $44 per barrel) of coal liquids. It must be noted that none of the estimates include taxes or royalties, except that by Harring and Tollefson (which includes taxes, but not royalties). It would be difficult to assess the value of taxes and royalties in each case but it is clear that if they were included, the overall cost estimates would be in the vicinity, or possibly above the current international price of oil. It has been mentioned in the previous chapter that a coal liquefaction plant would require a coal feed capacity far beyond that of a typical Canadian mine. It would seem appropriate therefore to include the cost of opening such a mine in the calculations which is frequently not done. The usual assumption is that coal will be purchased in sufficient quantities at current prices. For a commercial coal liquefaction plant, this assumption could prove optimistic.

The estimate in Table 4.8 by Dow Chemicals pertains to a U.S. location (Gulf Coast) and it was stressed at Dow's Calgary presentation that other locations (notably Canadian ones) would face somewhat higher costs. Figures 4.7 to 4.9 show the estimated sensitivity of the cost of coal liquids to changes in the desired rate of return, the construction cost and the cost of coal.

There are a number of other available cost estimates originating in the U.S. where more research has been undertaken to date in the area of coal liquefaction. Many of these figures are appreciably higher than those in Table 4.8. For instance, a study by the Oak Ridge National Laboratory[28] estimated the cost of coal liquefaction to be between $157 and $220 per $m^3$ ($25.00 and $35.00 per barrel) in terms of 1978 U.S. dollars (1981 Can. $234 to $328 per $m^3$ or $37.20-$52.05 per barrel). Exxon Research and Development Co. estimated in 1980 that a full-scale commercial plant would cost some (1980 U.S.) $3.7 billion and that the products would have to sell for an average equivalent of (1980 U.S.) $302 per $m^3$ ($48 per barrel) which in 1981 Canadian dollars is 387.65 per $m^3$ ($61.60 per barrel). A large-scale production of liquid fuels from coal would also necessitate modifications to existing refineries, adding further to the cost of the final product.

TABLE 4.8

COST ESTIMATES OF LIQUEFIED COAL PRODUCTION

| | | 1981 $ per $m^3$ ($/bbl)[a] |
|---|---|---|
| (i) | Herring and Tollefson[b]<br>Assumptions: 15,899 $m^3$/d capacity, 21.2% DCF rate of return, coal valued at (1980) $5.00/tonne, natural gas at 7.35¢/$m^3$ ($2.07/Mcf); for other assumptions, see text, pp. 22-31; | 159.21<br>(25.30) |
| (ii) | EMR[c] | 207.04 - 275.63<br>(32.90 - 43.80) |
| (iii) | Gregory et al.[d]<br>Assumptions: 22,247 $m^3$/d capacity, annual op. cost (1980) $800 mill; capacity (1980) $4.7 billion, Alta. location, no tax or royalty assumed; | 172.43 - 241.65<br>(27.40 - 38.40) |
| (iv) | Berkowitz[e] | 172.43 - 207.04<br>(27.40 - 32.90) |
| (v) | SNC Group[f]<br>Assumptions: 7,945 $m^3$/d capacity, using H-coal technology and Alberta coal at $16/ton, no tax or royalty included, no cost of mine included; | 188.79<br>(30.00) |
| (vi) | Dow Chemicals[g]<br>Assumptions: U.S. location, coal at 1979 (U.S.) $25/ton, daily product slate at 12,000 tons of coal a day: 33.8 MM SCF of gas, 10,800 bbls of LPG's, 13,000 bbls of naphtha and 17,655 bbls of fuel oil (for others, see source); | 185.01<br>(29.40) |

[a]Older estimates were translated into 1981 Canadian dollars using data in Appendix A.

[b]I.W. Herring and E.L. Tollefson, op. cit., p. 30.

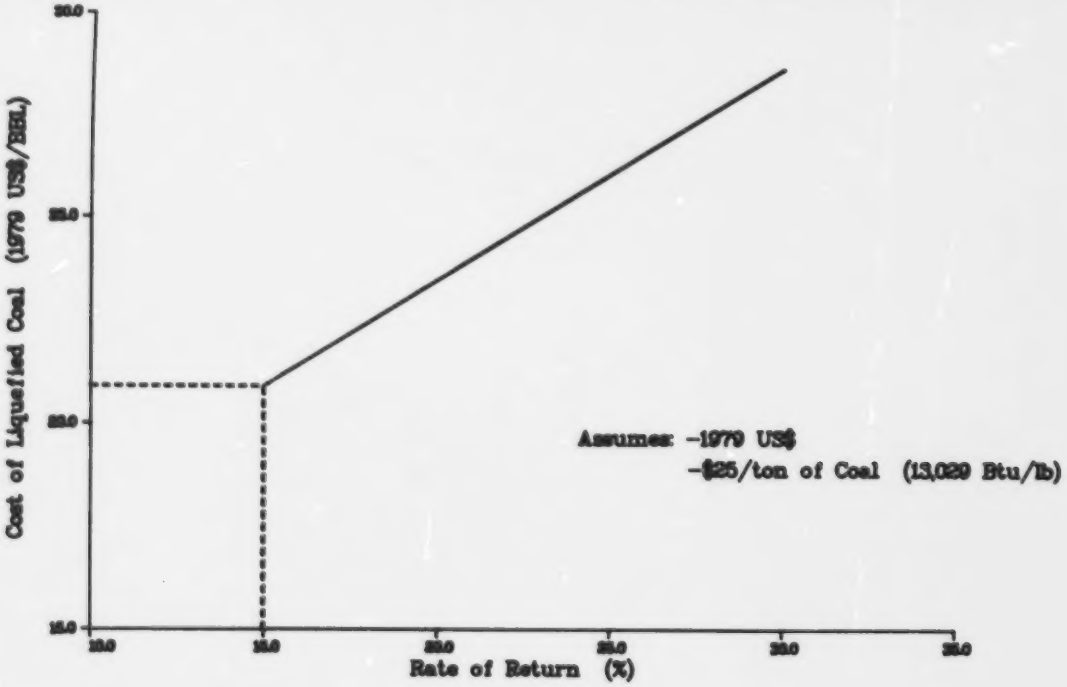
[c]Canada, EMR, "Discussion Paper on Liquid Fuel Options", op. cit., p. 22.

[d]R.W. Gregory, W. Kesel and J.M. Raisbeck, "Coal Liquefaction - A Viable Energy Production Method", a paper presented at 94th E.I.C. Annual Congress, Calgary, April 23 - 25, 1980.

[e]N. Berkowitz, Vice-Chairman of the Alberta Energy Resources Conservation Board, has made several public statements to this effect. See for instance The Globe and Mail and The Calgary Herald, both June 20, 1980.

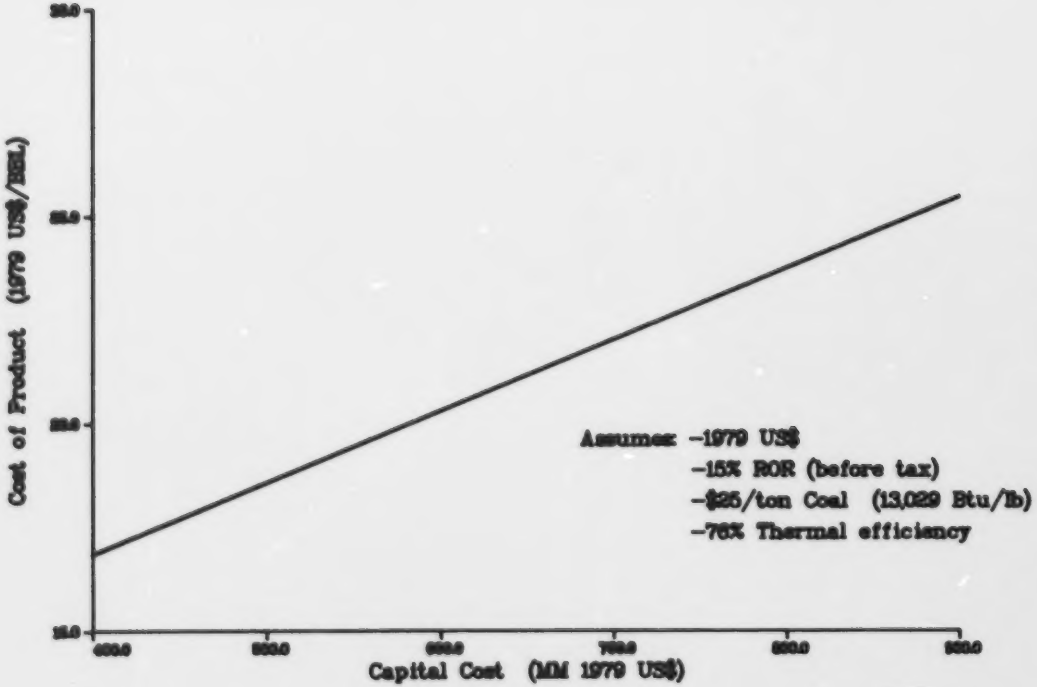
[f]SNC Group of Montreal, personal communication. The Group has carried out an extensive research in the area. See for instance a report in The Financial Post, September 19, 1981.

[g]G.A. Stuart, "The Economics of the Dow Coal Liquefaction Process" and Dow Chemical presentation in Calgary, December 10, 1980.



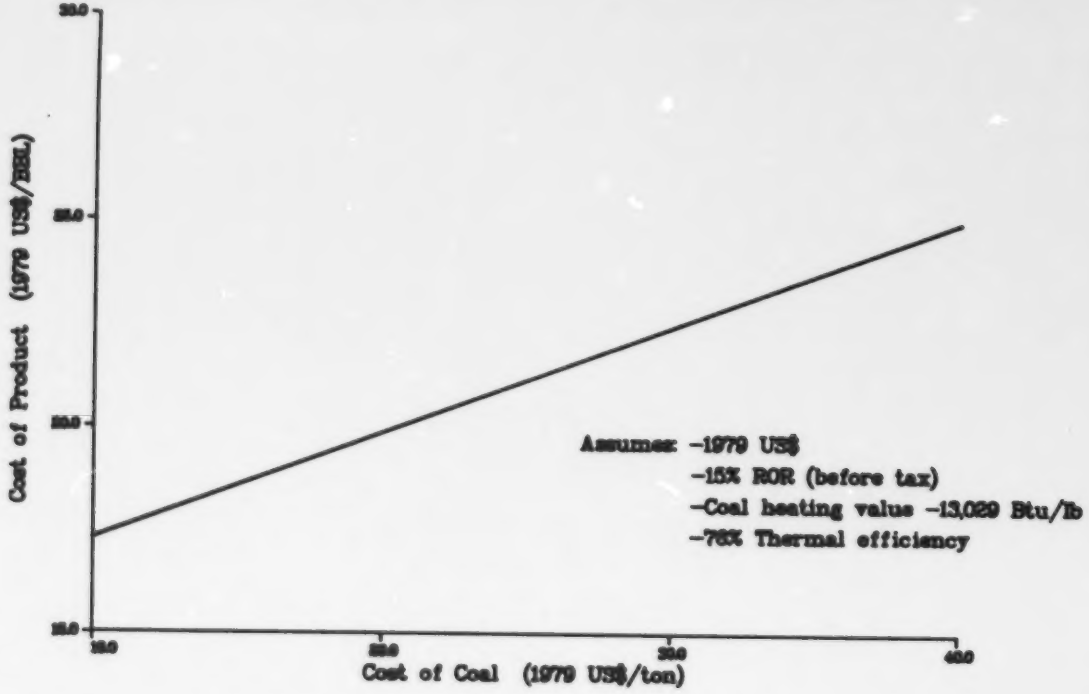

Source: Dow Chemicals

FIGURE 4.7: DOW COAL LIQUEFACTION PROCESS: EFFECT OF CHANGING RATE OF RETURN ON THE COST OF PRODUCT


Cost of Product (1979 US$/BBL)
Capital Cost (MM 1979 US$)
Assumes: -1979 US$
-15% ROR (before tax)
-$25/ton Coal (13,029 Btu/lb)
-76% Thermal efficiency

Source: Dow Chemicals

FIGURE 4.8: DOW COAL LIQUEFACTION PROCESS: EFFECT OF CHANGING CAPITAL COST ON THE COST OF PRODUCT


Cost of Product (1979 US$/BBL)
Cost of Coal (1979 US$/ton)
Assumes: -1979 US$
-15% ROR (before tax)
-Coal heating value -13,029 Btu/lb
-76% Thermal efficiency

Source: Dow Chemicals

FIGURE 4.9: DOW COAL LIQUEFACTION PROCESS: EFFECT OF CHANGING COST OF COAL ON THE COST OF PRODUCT

It is clear that coal liquids will be expensive but precisely how expensive we will not be able to tell before an actual commercial operation begins. The task now is to bring the technology to a stage of commercial readiness so that a full-scale plant can be designed with an acceptable level of risk. In this aspect coal liquefaction is not unlike the oil sands production in its beginnings in the 1960s and the 1970s. Although the production technology was known, the Suncor plant (then G.C.O.S.) did not turn a profit for a long time after its commencement in 1967. Also, various technological problems have plagued the Syncrude plant following its inception in 1978, with the plant still not operating at the designed full capacity in 1982. Early optimistic cost estimates of the production of oil from the oil sands, too, kept being revised upwards to the levels of the world market price for oil prevailing at present. Thus, although coal liquefaction appears to be a technologically mature alternative, other fuels discussed here could seemingly be produced at a lower cost. Further developments will likely depend on technological improvements and the changes in the world price of oil. In the face of highly insecure foreign oil supplies, however, coal liquefaction, like increased oil sands production, could become a secure long-term alternative source of transportation fuels. The potentially higher cost of such fuels would be the premium paid for the security of domestic supplies.

### 4.7 Hydrogen

One thing which can be said with certainty about hydrogen is that it is now being taken seriously as an alternative fuel, albeit with a somewhat more distant horizon. It is no longer foreseen, as it was in 1976, that there would be 15 oil sands plants operating in Canada by the turn of the century. The mood now is characterized by a long-term search for alternatives to crude-oil-derived fuels, many of which are renewable. While methanol could be considered as a medium-term alternative, hydrogen is an alternative for the long-term, most likely beyond the year 2000.

An economic assessment of hydrogen as a fuel is difficult; more difficult in fact than that of the other fuels discussed above. We are faced with a much greater technological uncertainty in the case of hydrogen than, say, in propane or methanol. It is true that experiments have been carried out and that research is currently under way and much has been accomplished. Yet the amount of general technical knowledge and expertise assembled to date is smaller relative to other alternatives. Short of unforeseen technological breakthroughs, therefore, we cannot expect that hydrogen as a fuel will be at the same

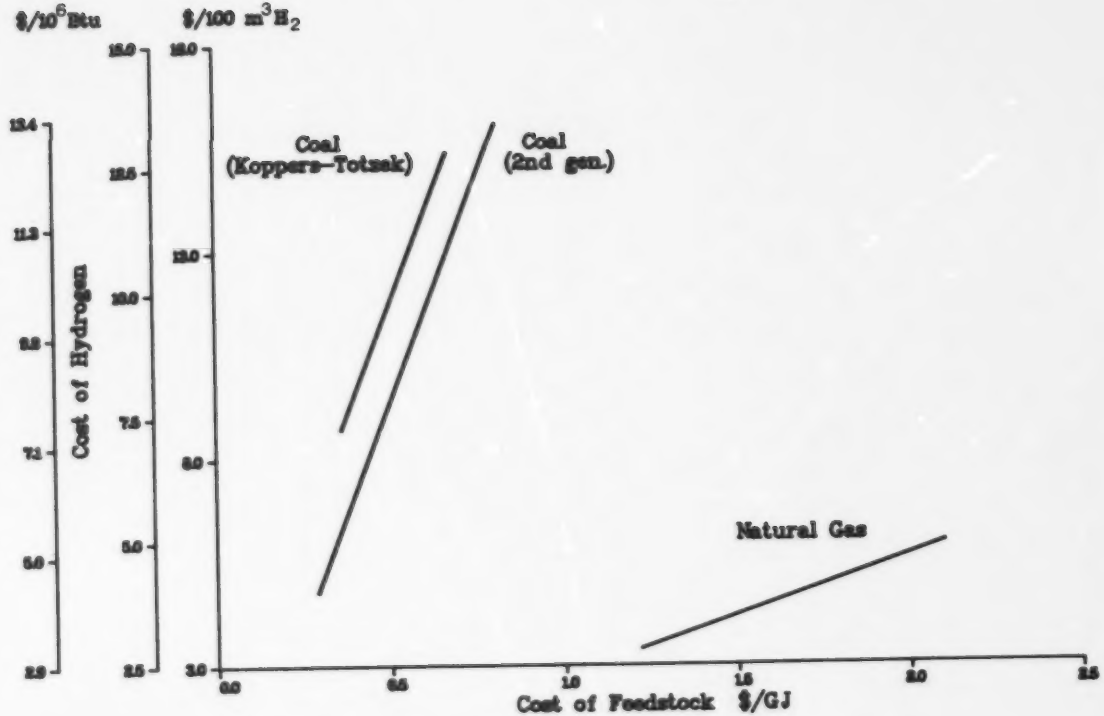
state of readiness for wide-spread application as other alternatives are now or are likely to be in the next ten to fifteen years.

Actual cost estimates for hydrogen are very scarce and unreliable. If hydrogen were to be produced from water via electrolysis, then the main component of production cost would be the cost of electricity. It is often asserted that cheap hydroelectricity will be available, especially in the large consuming provinces of Quebec and Ontario. Nuclear electricity will not be particularly cheap but Canada should not have a shortage of either electricity or water. Theoretically, hydrogen may in fact offer considerable advantages over electricity in terms of storage and transportation.

U.S.-based Billings Energy Corporation (acting as a consultant to the U.S. Department of Energy) estimated in 1980 that the cost of gaseous hydrogen for use in internal combustion engines would be the equivalent of 25 cents (US) per litre (95 cents a gallon). Liquid hydrogen, on the other hand, would be about four times as expensive as jet fuel. The Canadian Hydrogen Energy Society has put the estimate of hydrogen cost at (1980) 28¢/litre ($1.25 per gallon) of gasoline equivalent if cheaper off-peak electricity were utilized.[29] The Society suggests that, if (1980) $84 billion worth of investments were undertaken between now and the year 2000, enough hydrogen could be produced in Canada to meet all transportation needs in the country.[30] Another, more detailed, Canadian analysis estimated the comparative unit production cost of hydrogen from natural gas and coal.[31] Figure 4.8 shows the estimated sensitivity of the production cost of hydrogen to the cost of feedstock and the type of production (from natural gas or coal, using the Koppers-Totzek gasification method or second generation coal).

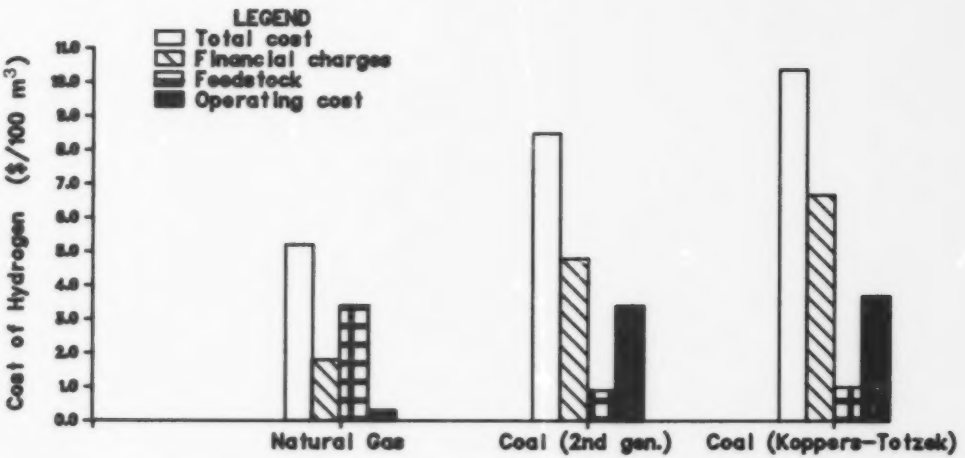
It can be seen from Figures 4.10a and 4.10b that, although natural gas is the more expensive feedstock, hydrogen production from natural gas appears much cheaper than from coal. But since the efficiency of converting natural gas to hydrogen is only about 65 per cent, it would seem that the embodied energy in natural gas would be better used in the form of natural gas than hydrogen.[32] Converting natural gas into hydrogen for the purpose of obtaining a transportation fuel thus does not seem to be a very sound engineering or economic practice since the former can be used in transportation more readily and efficiently in the form of methanol, propane or CNG.

The latest research effort in the area of hydrogen as a fuel in Canada is the 8-volume report of the Ontario Hydrogen Energy Task Force




Source: P. Bailey, op. cit., p. 82

FIGURE 4.10a: COMPARATIVE PRODUCTION COSTS OF HYDROGEN




Source: P. Bailey, op. cit., p. 62.

FIGURE 4.10b: COST COMPONENTS OF THREE HYDROGEN PRODUCTION PROCESSES

released last September. The recommendations of the Task Force center around an early decision for additional hydrogen-committed nuclear power capacity and the fact that, relative to the cost of energy from fossil fuels, the cost of electricity from nuclear power is expected (by the Task Force) to decline. However, because of the long lead time (close to 15 years) required to install a new major electricity generating capacity, a decision regarding new nuclear capacity would have to be made this year, in order to see hydrogen penetrating the transportation fuel market by the middle of the next decade. Table 4.9 shows the estimated production cost of hydrogen from three processes by the Task Force (cost of storage excluded) at present and in the future.

TABLE 4.9

PLANT GATE COST OF HYDROGEN SUPPLY (NEW PLANT)
(1980 dollars per GJ)

| Source | 1980 | 1980 | 2000 | 2025 |
|---|---|---|---|---|
| Low Estimate | | | | |
| Electrolysis | 8.2 | 7.5 | 5.6 | 6.1 |
| Steam-methane reforming | 4.9 | 7.9 | 10.7 | 12.9 |
| Coal | 9.1 | 9.7 | 10.3 | 11.2 |
| High Estimate | | | | |
| Electrolysis | 8.2 | 8.1 | 6.6 | 7.2 |
| Steam-methane reforming | 5.4 | 9.8 | 11.8 | 18.1 |
| Coal | 9.8 | 10.7 | 11.5 | 13.1 |

SOURCE: Ontario, Ontario Hydrogen Energy Task Force, Hydrogen: A Challenging Opportunity, Synopsis, Toronto, Sept. 1981, Table 11.

It can be seen in Table 4.9 that on the basis of forecast decline in electricity cost, the plant gate cost of electrolytic hydrogen is projected to decline substantially by the year 2000, while the costs of hydrogen from natural gas (present way of obtaining hydrogen) or coal are projected to rise. Although these estimates are interesting, we still do not have reliable estimates of the cost of transporting, distributing and storing hydrogen, and of the cost of

converting existing automobiles, or of manufacturing new hydrogen-fuelled vehicles.

### 4.8 Concluding Comment

The cost estimates for the alternative liquid fuels presented here are, of course, only tentative. The development of these fuels will only materialize within an institutional framework wherein investors find it possible and attractive to invest in the production of the fuels and consumers are encouraged to switch to them. It is worth noting that it is in the market place that the development and marketing problems associated with the alternative fuels would be solved in an efficient manner. Once the market signals are 'right', owners of resources, fuel refiners, and vehicle and home furnace manufacturers may be expected to undertake the necessary research and development required to minimize the technical risk of production. Once new products designed to run on alternative fuels are developed at competitive prices, consumers, too, may be expected to make the switch.

Figure 4.11 summarizes the current cost estimates of the alternative transportation fuels considered here and compares them to the cost of gasoline derived from conventional oil. In the case of each of the alternatives, a 'base-case type' unit cost has been selected and the comparison is made on the basis of usage in transportation (ie., the costs of conversion, distribution, etc. are included). When making a comparison between the fuels listed, it should be kept in mind that even for the base-case, very different numbers can be obtained depending on the various assumptions which must be made for more detailed calculations. The estimates contained in Figure 4.11 are thus no more than 'ball-park figures' which should serve the purpose of comparing orders of magnitude only. Figure 4.11 shows the cost of the alternatives as 'equivalents' to gasoline produced from crude oil (weighted average cost of domestic and imported oil of \$177.2/$m^3$ or \$28.16/bbl in fall, 1981), and used in transportation. If for instance the cost of propane was found to be 16¢/litre (Calgary, Fall, 1981), we add to this figure a penalty for conversion cost and subtract savings due to lower maintenance cost obtaining an equivalent (or comparable) figure to gasoline of 21¢/litre of propane used in transportation. Since gasoline sold for 31¢/litre at the same time (obtained from crude oil at \$177.2/$m^3$ or \$28.16/barrel), the 21¢/litre of propane is thus 'equivalent' to crude oil priced at \$120.07 per $m^3$ (or \$19.08 per barrel).

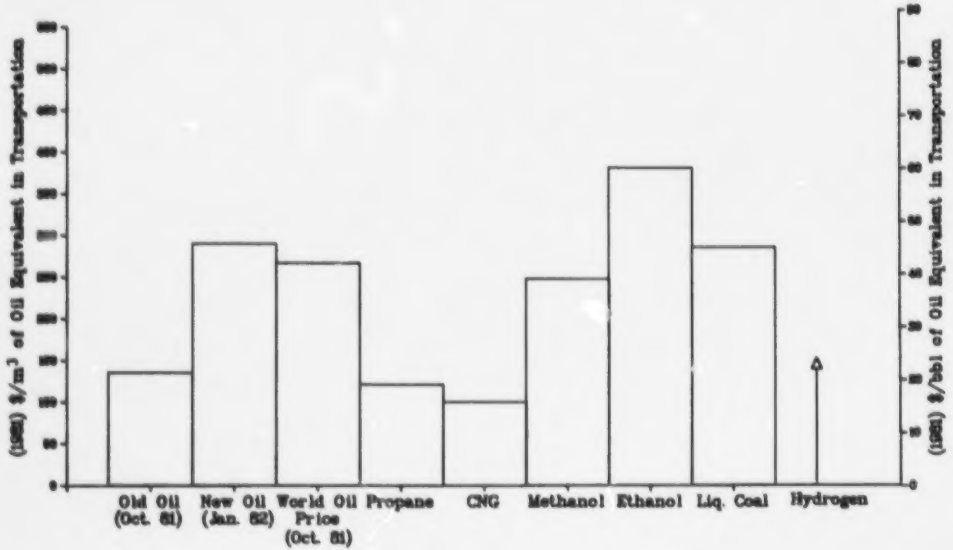



Figure 4.11: Comparative Cost of Alternative Fuels

It can be seen in Figure 4.11 that in Canada, we have two short-term alternative fuels--propane and compressed natural gas--available at sufficient quantities and at a lower cost than the current comparable cost of gasoline. Indications are that in larger Canadian cities such as Toronto, Vancouver, Winnipeg, Calgary and elsewhere, some motorists have already begun switching away from gasoline albeit thus far only in small numbers.

There are, further, two available medium-term liquid fuels--methanol and liquefied coal--which may be used during the interim period within which Canada switches its energy base entirely (away from the hydrocarbons) if and when such a switch is deemed timely and appropriate. Ethanol's production seems too expensive, often estimated at a higher level than indicated in Table 4.4, and the cost of using and producing hydrogen on a large scale is at present too uncertain to be assigned a specific number.

As suggested at the beginning of the chapter, it would be interesting to compare these (marginal or incremental) cost estimates of producing alternative transportation fuels to the estimates of marginal cost of gasoline savings due to improved vehicle fuel efficiency, since clearly, these are the two alternative ways of reducing our current consumption of gasoline. Improved fuel economy can be expressed in dollars per litre of reduced fuel consumption. This can be done in the following way.[33] The 1979 model year was selected as the starting year for comparison because it was the most recent year for which complete production and technological data were available. The reduced fuel consumption for cars was calculated on an annual incremental basis, showing the relative reduction in fuel use from one model year compared with the previous model year. The incremental consumer cost of greater fuel economy was then divided by the discounted incremental lifetime fuel savings of each vehicle each year. As a result, the marginal consumer cost of fuel saving was derived. It has been estimated that this cost rises from about 15¢/litre in 1980 to more than 93 (1980)¢/litre in the year 2000.[34] The marginal cost values for the period from 1980 to 2000 are shown in Figure 4.12. The marginal cost of saving a litre of fuel increases mainly because of the relative reduction of fuel consumption as fuel efficiency increases over time. The marginal cost of any fuel-saving technological improvement will therefore be much less now when that technology can reduce fuel consumption by proportionately greater amounts. The timing and the magnitude of such investments will produce a curve with shape similar to that in Figure 4.12. As initial savings of fuel are realized, the relative reductions decline significantly, adding more and more to

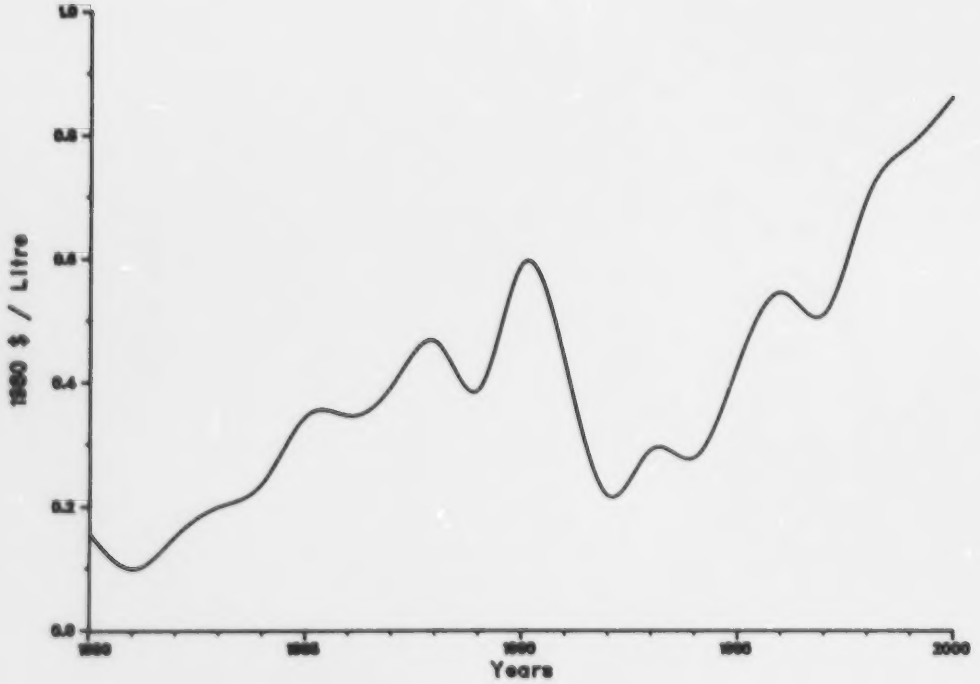



FIGURE 4.12: Marginal Cost of Fuel Saved

SOURCE: Based on R. H. Shackson and H. J. Leach, op. cit., Tables 32 and 33.

cost. When an average fuel efficiency of 7.5 to 6.8 litres per 100 kilometres (38 to 42 miles per gallon) or more is reached (which is assumed to be the case by the year 2000), further percentage increases in fuel economy produce very small savings.

An interesting comparison can be made between the costs of the two alternatives. For reasons of policy, this is a rather important piece of information. It can be seen that on the basis of cost alone, improved vehicle fuel efficiency, particularly during the early part of this decade, appears to be the preferred alternative. But as initial fuel savings are realized, further improvements tend to be more and more costly. In other words, the marginal cost curve for a more fuel efficient design eventually rises steeply. Assuming no changes in constant dollar relative prices between the two types of cost,[35] the cost levels of the alternative fuels discussed in this chapter could be projected across the diagram in Figure 4.12 to see which fuels and when will be cost-preferred to greater fuel conservation. The estimates show that strictly on the cost basis, improved fuel efficiency would be the preferred investment until approximately 1987, particularly in eastern Canada. This does not mean, however, that the switch to propane or CNG is uneconomic now. For certain fleet operators, converting to either of the two fuels is viable at present, with pay-back period as short as one year followed by considerable fuel bill savings.

One last caveat for those interested in the relative prices of alternative fuels is in order. Currently, the system of collecting revenues by various levels of government is done rather effectively through taxes imposed on transportation (and heating) fuels collected at the pump. The collection of a provincial sales tax on transportation fuels is, presumably, intended to pay for construction, operation and maintainance of roads and highways and thus it would only be fair to see the tax levied on all transportation fuels. If the consumption of gasoline were to be reduced due to a large-scale switching by vehicle owners to other fuels, governments cannot be expected to wait too long before imposing additional taxes on alternative fuels to keep their revenues from falling. Relative fuel prices would thus again be changed with previous incentives diminishing or disappearing. The case of gasoline and diesel can serve as an example. This real possibility of a relative price increase for a given alternative fuel once motorists have converted to its use, is perhaps the strongest uncertainty presently facing potential propane and compressed natural gas users. Without this obstacle, many more motorists would find these fuels more attractive than gasoline today.

**Footnotes**

[1]E. N. Merrow, K. E. Phillips and C. Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, Rand Corporation report R2569 (prepared for DOE), 1981. The report highlights the severe underestimation of plant cost estimated at different stages of development of chemical process plants. The authors find that cost estimates are not distributed symmetrically in practice.

[2]See R. H. Shackson and H. J. Leach, Maintaining Automotive Mobility, Arlington, Virginia: Mellon Institute, 1980, p. 14, where they conclude that "Both synfuel production and improved fuel economy should be pursued during the next decade as one integrated strategy to minimize the cost of mobility."

[3]Published Canadian sources which contain specific cost information include the following: J. E. Feick and D. J. McConaghy, "The Relative Economics of Recovering and Upgrading Alberta's Hydrocarbon Resources," The Journal of Canadian Petroleum Technology, April-June 1976, pp. 19-26; or Ontario, "Liquid Fuels in Ontario's Future," prepared by Canadian Resourcecon, Ltd., 1978; or "Liquid Fuels from Renewable Resources," prepared for Government of Canada by InterGroup Consulting Economists Ltd., Winnipeg, 1978; or Canada, Department Energy, Mines and Resources, "Discussion Paper on Liquid Fuel Options," (Ottawa: Minister of Supply and Services, 1980). One very recent study has addressed the specific question of employing wood-using techniques in B.C. See A. H. Hansson, "An Economic Analysis of Methanol Production by Wood-Using Techniques in British Columbia." Resources Paper No. 54, Vancouver, B.C.: The U.B.C. Programme in National Resource Economics, June 1981. Additional information (both technical and regarding costs) has been obtained from the Minutes of Proceedings and Evidence of the Special House of Commons Committee on Alternative Energy and Oil Substitution (1980), various issues, nos. 1 to 36; and from the industry.

[4]The energy content and energy efficiency characteristics of methanol can then be reflected by multiplying an initial cost estimate by factors of 0.485 and 1.25. Combined, these two factors give a value of 0.606: whereas a litre of gasoline may power a vehicle for 10 kilometres, a litre of methanol would carry it only 6.06 kilometres. Alternatively, it takes 1.65 litres of methanol to drive an equal distance as with one litre of gasoline. Hence to be cost-comparable, methanol must be priced at 60 percent (1 ÷ 1.65) of the price of gasoline.

[5]This price of methanol is a delivered price to Montreal, Toronto, Winnipeg, Edmonton, Calgary or Vancouver via 30,000 (U.S.) gallon rail cars, quoted by Alberta Gas Chemicals of Edmonton in September, 1981.

[6]Quoted in P. Ashton, op. cit., p. 34.

[7]Assuming a lifetime vehicle mileage of 80,000 miles and an average methanol fuel efficiency of 13 miles per gallon. See Ibid.

[8]T. O. Wagner et al., op. cit., p. 260. The estimate, however, pertains to ethanol but it can be assumed comparable with methanol.

[9]For the years 1982 through 1986, predicted annual percentage increases in consumer gasoline prices run as follows: 16.65, 17.62, 14.89, 12.72 and 12.81, respectively. See the table prepared by the federal Department of Energy, Mines and Resources reprinted in The Globe and Mail, September 3, 1981.

[10]No adjustments have been attempted to account for a possible cost differential due to the U.S. versus Canadian location of the plant. Where required, data have been translated into 1981 Canadian dollars using exchange and inflation rates listed in Appendix A.

[11]See R. Overend, op cit., pp. 3 and 6.

[12]See Marilyn Herman, Director of the U.S. National Alcohol Fuels Commission in her presentation to the last Congress meeting of the American Association for the Advancement of Science, quoted in The Globe and Mail, January 6, 1981.

[13]Canada, The House of Commons, op. cit., pp. 127-128. The publication of the Committee and particularly the Minutes of Proceedings and Evidence contain a number of cost estimates by various witnesses.

[14]If anything, this assumption may introduce a slight bias in favor of ethanol (gasohol). See for instance a similar conclusion drawn by F. H. Sanderson in "Benefits and Costs of the U.S. Gasohol Program," Resources (published by Resources for the Future), July 1981, pp. 3-4.

[15]The source of Table 4.4 is two years old. While the vertical axis has been translated into current Canadian equivalent, no attempt has been made to update the horizontal axis. In September 1981 average grain prices were within the following ranges: wheat--$4.90 to $5.44 per bushel; barley--$2.77 to $3.00 per bushel; and corn--$4.75 to 4.85 per bushel (prices obtained from Alberta Wheat Pool and Federated Co-Op).

[16]Communications with Mohawk Oil.

[17]While some estimates put the propane fuel efficiency of a dual fuel system equal with that of gasoline for city driving, but about 10 percent lower for highway travel, others feel that the reduction for highway travel could be as high as 20 percent. If desired, a small penalty could therefore be worked into an economic

assessment of propane for an individual case when the share of highway travel can be estimated. A vehicle tuned to an exclusive use of propane can be assumed to have an equal fuel efficiency as one powered by gasoline.

[18]Additional extra cost to companies with large fleets could include renting or purchasing a bulk storage tank. Such companies, however, could obtain propane for less than the regular retail price. For other users it is assumed that regular retail outlets are or will soon be available. Existing propane outlets in Canada are listed in Propane Outlets in Canada, Energy, Mines and Resources Canada (date not given).

[19]No cost of money is assumed here but when known, it could easily be included in an actual calculation.

[20]There are some indications that the price of propane could become subject to regulation if it in fact keeps increasing with the price of crude oil. See for instance a letter by the federal Minister of Energy (February 10, 1981) to the Propane Gas Association of Canada Inc.

[21]The lower figure has been quoted by CNG Fuel Systems Ltd.; and the higher by D. Sheraton, head of B.C. Research's natural gas conversion division. By summer of 1981, no conversion shops existed and thus the cost is only an estimate. CNG Fuel Systems, however, opened its first shop in Calgary in September and plans to open soon a similar facility in Vancouver and also in Toronto.

[22]More than half of the conversion cost is accounted for by parts and about 90 percent of the parts are currently imported (mainly from Italy). This means that for the time being at least, the conversion cost will also be to some extent determined by the strength of the Canadian dollar. In the future, however, the percentage of imported parts should be reversed as CNG Fuels Systems start producing most of the items in Canada under licence.

[23]Initially, CNG will start to be marketed in Calgary and Edmonton by Husky Oil service stations. Negotiations are also under way between CNG Fuel Systems and a major distributor in eastern Canada for marketing CNG there.

[24]See for instance the condition derived by the House of Commons Committee on Alternative Energy, op. cit., pp. 114-116.

[25]R.W. Gregory et al., op. cit., p. 6. The operating cost estimate for the coal liquefaction plant includes significant costs of coal (estimated at 1980 $240 million/year) and natural gas (1980 $350 million/year).

[26]No cost premium has been added to the estimates originating in the U.S. and pertaining to U.S. rather than Canadian plant locations.

[27]They may particularly differ with respect to the mix of the final liquid products and the assumed market values for them.

[28]L. E. McNeese, R. Salmon and H. D. Cochrane, "Recent Developments in Coal Liquefaction in the U.S.", Oak Ridge Nat. Lab. and the U.S. Department of Energy, February, 1979.

[29]CHES Newsletter, October 1980, p. 8.

[30]Ibid. The Newsletter bases the conclusion on the results of two uncited studies carried out by Ontario and Quebec Hydro.

[31]P. Bailey, op. cit., pp. 62-63.

[32]The energy content of one cubic metre of natural gas is 35.575 MJ, while one cubic metre of hydrogen contains 12.10 MJ.

[33]R.H. Shackson and H. J. Leach, op. cit., pp. 60-67, esp. Tables 32 and 33.

[34]Ibid.

[35]This assumption may hold for a shorter period of time but may be unrealistic for the entire 20 years shown on the diagram in Figure 4.10.

## Chapter 5

# THE ALTERNATIVE FUELS: SUPPLY AND DEMAND PROSPECTS

### 5.1 Introduction

In this chapter, possible future developments relating to the supply and demand of the alternative fuels to 1990 are discussed. Since no significant contribution in the area of transportation fuels will be made by hydrogen or liquified coal within this time interval, the analysis is restricted to methanol, ethanol, propane and compressed natural gas.

Assessing future supply and demand of any commodity is uncertain, particularly if the price of the commodity in question is uncertain. As more and more motorists switch to the use of some of the alternatives discussed, upward pressure can be expected on their prices. Government policies, too, can be expected to change future prices of alternative transportation fuels if government revenues (taxes on gasoline sales) are eroded due to decreased use of gasoline and increased use of alternative fuels. Higher fuel prices, in turn, cause greater availability, but restrict quantities demanded by consumers.

It is anticipated that although there will be conversions of private vehicles from gasoline to alternative fuels, for reasons of cost the bulk of initial conversions will be undertaken by commercial vehicle fleets. There is a total of some 12.5 million vehicles in Canada (1979) of which nearly 2 million are commercial. Though they make up only one-sixth of the total vehicle market, commercial cars and trucks consume about one-third of transportation fuel (38 162 $m^3$ or 240,000 bbls per day); and currently, about 30 to 40 percent of gasoline is sold to commercial customers with their own storage facilities. The remaining 60 to 70 percent is sold at the retail pump.[1] It is clear therefore, that the commercial market is large and well established. The initial marketing effort should thus concentrate on this market.

Regional dimensions of the supply and demand of the alternative fuels will also be presented. Currently, only one province (Alberta) is self-sufficient in the production of crude oil needed to refine gasoline for transportation. Regional aspects of alternative fuels are

therefore important, particularly in the main consuming provinces of Ontario and Quebec.

## 5.2 Methanol

It was mentioned earlier that methanol is one of the medium-term alternative transportation fuels available in Canada. Although currently producing some 440 thousand metric tonnes (1.2 billion gallons) of methanol per year, Canada is not a major user of methanol and much of the planned additions to production capacity is geared to the export market, mainly to the U.S. and Japan. At the present, all Canadian methanol is a chemical grade methanol which has a higher purity than would be required of a fuel-grade methanol used in transportation.

Table 5.1 shows estimated Canadian methanol output and disposition between domestic use and exports. (Due to the currently small number of Canadian methanol producers, no official statistics are available pertaining to methanol output, consumption and exports. Data contained in Table 5.1 are therefore only estimates). It can be seen that only some 45 percent of methanol produced in 1980 was used domestically, with the rest exported.

Regional breakdown of overall Canadian methanol production is shown in Table 5.2. This table also lists planned additional (mostly under construction) capacity. All new plants will use natural gas as feedstock and are located in the two western-most provinces. With the exception of the Biewag plant, all others are slated to produce chemical grade methanol, mostly for exports.

Although the additions to production capacity amount to a vast increase (tripling by the end of 1982), this increase is nevertheless insignificant if methanol were to be used as a transportation fuel, even on a very modest scale. In a blend with gasoline, methanol could for instance displace 5 percent of gasoline if a mix of 95 percent gasoline and 5 percent methanol were used. This percentage could be less (3 percent) or more (up to 15-20 percent), but with a higher methanol content of the blend, cold weather starting problems (discussed in ch. 3 above) become more severe. During 1980, for example, Canadians used 38.04 billion litres of gasoline (242,122 thousand barrels) in road transportation. If only a modest 5 percent of this amount were to be displaced by methanol, the additional methanol production capacity required would be some 1,520 thousand tonnes per year, which is nearly twice the total expected Canadian capacity by the end of 1982. Such expanded use of methanol would call for more than two additional plants

TABLE 5.1

CANADIAN METHANOL PRODUCTION AND CONSUMPTION[a]
(thousand tonnes per year)

| Year | Production | Consumption | Exports[b] |
|---|---|---|---|
| 1975 | 440 | 135 | 305 |
| 1976 | 440 | 146 | 294 |
| 1977 | 440 | 159 | 281 |
| 1978 | 440 | 172 | 268 |
| 1979 | 440 | 195 | 245 |
| 1980 | 440 | 200 | 240 |
| 1981 (est.) | 440 | 205 | 235 |

SOURCE: CERI; industry and government sources.

[a]Since no official statistics exist pertaining to Canadian methanol output, consumption and exports, these data must be considered to be estimates only.

[b]Mainly to the U.S. and Japan.

TABLE 5.2

EXISTING AND PLANNED CANADIAN METHANOL CAPACITY
EXISTING CAPACITY

| Company | Plant Location | Output Capacity (thousand metric tonnes/yr) | Year of Completion |
|---|---|---|---|
| Alberta Gas Chemicals | Alberta | 190 | 1974 |
| Alberta Gas Chemicals | Alberta | 190 | 1975 |
| Celanese | Ontario[a] | 60 | 1968 |
| Total output: | | 440 | |
| Planned Additional Capacity | | | |
| Alberta Gas Chemicals | Alberta | 380 | 1982 |
| Ocelot Industries | B.C. | 400 | 1982 |
| Celanese & PanCanadian | Alberta | 700 | 1982 |
| West Coast Transmission | B.C. | 375 | 1983 |
| Alberta Gas Chemicals | Alberta | 380 | 1986 |
| Biewag Energy Res. Ltd. | Alberta[b] | 1 665 | ? |
| Total additional plant capacity | | 3 900 | |
| Grant Total | | 4 340 | |

SOURCE: Canadian Energy Research Institute; industry and government sources.

[a]This plant may be closed once the new facility of Celanese and Pan Canadian opens near Edmonton in 1982.

[b]This plant is at a pre-application stage and its proposed capacity is not certain. Estimated cost is $700 million.

of the size currently under construction near Edmonton by Celanese Canada and Pan-Canadian Petroleum. The use of richer methanol blends would, of course, necessitate an even greater expansion of methanol production, while the use of straight methanol fuel would require an enormous expansion of production capacity.

If, out of the available alternatives, methanol gains preference as a major transportation fuel for the future, then new methanol plants should be constructed such that the overall cost per litre is minimized. This may mean that new plants may have to be constructed either near large markets for methanol (Ontario, Quebec), or near where the main feedstock is found, depending whether it is cheaper to transport the feedstock or the final product. In 1980, for instance, 66 percent of Canadian motor gasoline consumption occurred east of the Manitoba-Ontario border and 57 percent in Ontario and Quebec alone.[2] In addition to being close to market, methanol plants in Ontario or Quebec could use feedstocks other than natural which are locally available and are more evenly distributed across Canada than natural gas or coal. These feedstocks are biomass[3], peat or municipal solid waste.

A recent study estimated that the potential energy contribution from various biomass resources in Canada is in the neighbourhood of 174 percent of what total Canadian fossil fuel energy requirements were in 1978.[4] This is a large potential and it should be emphasized that the biomass resources included in the estimate are all renewable and more evenly distributed across the various regions of the country than natural gas or coal.[5] Other studies, too, support the contention that the potential of biomass to produce fuel in Canada is several times our energy consumption.[6] It has been estimated that Ontario alone could produce up to 16,000 tonnes per day (5,328 thousand tonnes per year) of methanol from indigenous municipal solid waste, forest residue, poplar plantations and lignite.[7] Thus the production potential is there. However, only clear market signals will lead to its development.

The future supply and demand balance for methanol in Canada depends on the penetration of methanol into the transportation fuel market both at home and abroad. A world-scale plant like the one planned by Biewag Energy Resources (1,665 thousand tonnes/yr.), could provide three times the methanol needed for a 5/95 percent methanol/gasoline blend for all four western provinces given current consumption levels. In Ontario and Quebec, where more than one half of Canadian transportation fuel consumption takes place, methanol could be produced

from either peat (Ontario), municipal solid waste, lignite or from wood. Since other alternatives (propane and compressed natural gas) are more cost-attractive in the near-term, however, it is not expected that methanol will account for a large share of the transportation fuel market before the next decade. Much like ethanol (discussed below), its best use within this decade might be as an extender of gasoline supplies through blending, in those regions of the country where possible shortages of gasoline may occur, or where excess methanol-producing capacity may exist.

### 5.3 Ethanol

Production of ethanol on a commercial basis was begun in Canada in October, 1981, by Mohawk Oil Co. in Manitoba. Prior to that time, ethanol (ethyl alcohol) was produced only for non-fuel purposes, such as for use in solvents, perfume, antifreeze, hospitals, laboratories, etc. Using locally grown feed-grade barley, Mohawk Oil's plant at Minnedosa is initially producing some 8 million litres (1.76 million gallons) of ethanol per year using 22,000 tonnes of barley. With anticipated expansion, the plant's annual output should increase within a year to 15 million litres (3.3 million gallons) using between 30,000 and 40,000 tonnes of barley.

The ethanol is mixed with regular unleaded gasoline in a 10/90 percent blend to obtain gasohol which is being sold at 15 out of 18 of Mohawk's retail gasoline outlets in Manitoba. The company operates some 340 retail gas stations in western Canada, and plans exist for a further expansion of its gasohol production and distribution capacity in western Canada.

To put Canada's production of ethanol into perspective within the transportation market, note that during 1980 Manitoba motorists consumed 1.611 billion litres of gasoline (354.3 million gallons). The ethanol volume currently being produced thus accounts for about 0.5 percent of total gasoline use in Manitoba. This will rise to almost one percent when ethanol capacity is expanded. In terms of overall Canadian gasoline use, Manitoba's ethanol output, when expanded within a year, will account for about 0.04 percent. Admittedly, this is not very much but it is a beginning. What is being proven in Manitoba is that ethanol (in the form of gasohol) can be used to extend the domestic supply of automotive fuel should a real shortage of crude oil develop.

A large ethanol plant can be constructed in two years, a small plant in one year. As mentioned above, the output of ethanol could be

increased in the future, perhaps up to 150 million litres (32.9 million gallons) per year during the next three years.[8] New ethanol plants can be built anywhere in Canada where biomass grows, with obvious advantages for locations currently supplied by shipped-in gasoline. It must be recognized, however, that ethanol can only be used as an extender of gasoline supplies; it is not an alternative in the true sense. Its advantage is that when used in the form of gasohol, engine modifications are not required. The supply limitations, however, are too great to be overcome during this decade. If the current (1980) Canadian consumption level of automotive gasoline were to be extended by only 10 percent, to run all vehicles on gasohol rather than on gasoline, the present ethanol production capacity would have to be increased by a factor of 480 (256 if next year's expanded capacity is considered).

There is, however, a large scope for research in ethanol production. Crops other than grain could be used and production efficiency improved. Among the promising crops are Jerusalem Artichoke, sugar beets and aspen wood. In addition, use of other sources such as straw and saw dust, and conversion of cellulose to alcohol, could greatly increase alcohol yields.

### 5.4 Propane

In Canada propane and butanes are obtained almost exclusively from the processing of natural crude oils and gas and from the production of synthetic crude oil. Propane is thus a by-product and its output depends critically on the output of crude oils and natural gas.

Propane and butanes (liquid petroleum gases, LPG) are produced directly from crude oils and natural gas, and from a number of refinery processes. Significant sources of LPG are distillation of crude oils, hydrocracking, catalytic cracking, catalytic reforming, coking and petrochemical operations, with appreciable differences in the rates of LPG recovery from different sources. Although exceptions exist, in general, higher gravity crudes contain more LPG than lower gravity crudes. Table 5.3 shows typical LPG contents for several types of crude oil. Only about one quarter of Canadian propane output, however, is derived from crude oil with the rest being stripped off natural gas. Propane recovery from crude oil could be as high as 4 percent of the crude oil refinery throughput, while the recovery from natural gas can vary from zero to 15 percent, depending on whether the gas is 'wet' or 'dry'. Table 5.4 shows the level of propane production in Canada during the last ten years. On average, less than half of the output

has been consumed domestically with the rest exported, mainly to the U.S. and Japan. In 1980, for example, some 60 percent of the daily Canadian propane output was exported.[9]

TABLE 5.3

TYPICAL LPG CONTENT OF VARIOUS CRUDE OILS
(% of volume)

| | Alberta Sweet | Arabian Light | Synthetic | Tia Juana Medium |
|---|---|---|---|---|
| Propane | 1.07 | 0.45 | 0.10 | 0.50 |
| Normal Butane | 1.93 | 1.51 | 2.70 | 0.59 |
| Isobutane | 0.26 | 0.32 | 0.90 | 0.28 |

TABLE 5.4

PROPANE FIELD AND PLANT PRODUCTION IN CANADA
(thousands of $m^3$)[a]

| Year | British Columbia | Alberta | Saskatchewan | Canada |
|---|---|---|---|---|
| 1972 | 76.3 | 4 499.2 | 121.5 | 4 697.0 |
| 1973 | 99.2 | 5 100.4 | 116.2 | 5 316.0 |
| 1974 | 91.7 | 5 078.8 | 96.4 | 5 266.9 |
| 1975 | 82.0 | 5 404.6 | 88.7 | 5 575.3 |
| 1976 | 89.2 | 5 244.0 | 81.6 | 5 414.7 |
| 1977 | 91.3 | 5 346.5 | 78.7 | 5 516.5 |
| 1978 | 85.7 | 5 048.2 | 80.0 | 5 213.9 |
| 1979 | 81.1 | 5 551.6 | 76.0 | 5 708.7 |
| 1980 | 74.3 | 5 277.1 | 79.7 | 5 431.1 |
| 1981 (Jan. - Aug.) | 38.2 | 3 504.7 | 52.8 | 3 595.8 |

(Figures may not add due to rounding)

SOURCE: Statistics Canada, Catalogue 26-006, various years.

[a]To obtain the above values in barrels, use 1 bbl = 0.15899 $m^3$.

Domestically, propane is used mainly as a space-heating fuel, lumber, tobacco and crop-drying fuel, and in transportation. More than one-half of the propane used in Canada is for space heating (commercial, industrial and residential). The main component of the domestic demand for propane is therefore highly seasonal. Butanes are used for gasoline blending and in the petrochemical industry.

The use of propane as a transportation fuel in Canada is minimal in absolute terms as well as by international standards. The total number of vehicles operating in Canada on propane in 1979 was estimated at 8,760, or less than 0.1 percent of total vehicles in the country. Table 5.5 shows the estimates for each province.

It can be seen in Table 5.5 that in 1979 the Canadian ratio of propane to gasoline use by volume percent was only 0.15, compared with 0.92 in the U.S.; 10.4 (1978) for the Netherlands; 7.0 (butane, 1978) for Italy; and a target of 10.0 in New Zealand.[10] It can also be noted from Table 5.5 that in 1979, 88.5 percent of Canada's use of propane as a motor fuel was in Alberta and British Columbia. This is not surprising when one considers that, historically, propane has been cheaper than gasoline by a greater margin in those two provinces than in the rest of Canada. Table 5.6 shows the differences between gasoline and propane prices for all provinces in 1980.

Because various price incentives have been introduced to make propane more price-competitive with gasoline, it is generally expected that the use of propane in transportation will increase. Conversions to propane have been rising, especially in Ontario. There, in addition to the $400 grant (introduced in the National Energy Program), the provincial government has eliminated its road tax on propane sales as well as the sales tax on exclusively propane-powered vehicles. In the spring of 1982, conversions to propane in Ontario were estimated at more than 12,000 and were proceeding at a high enough rate to suggest that the goal of 40,000 propane-powered vehicles by 1985 (set by the Ontario's "Drive: Propane" program) may be reached well before that time.[11] The prime candidates for the conversion process are commercial fleet vehicles and it has also been estimated that various government fleets (mainly federal and provincial) may be converted to propane. Table 5.7 shows one estimate of the number of propane conversions for all levels of government during this decade.

Commercial propane-powered vehicles were also forecast to increase in numbers from about 8,590 in 1980 to 16,300 by 1985 and 65,100 by 1990.[12] This would bring the total number of vehicles converted to propane (government and commercial) to 21,900 by 1985 and

TABLE 5.5

PROPANE USE IN ROAD TRANSPORTATION IN CANADA (1979)

| | Atlantic | Quebec | Ontario | Manitoba | Saskatchewan | Alberta | British Columbia | Canada |
|---|---|---|---|---|---|---|---|---|
| Estimated no. of propane-powered vehicles (rounded) | -- | 85 | 45 | 385 | 475 | 4,975 | 2,795 | 8,760 |
| % of total propane used in vehicles | -- | 1.0 | 0.5 | 4.5 | 5.5 | 57.6 | 30.9 | 100 |
| Propane-to-gasoline use ratio by volume % | n.a. | 0.007 | 0.002 | 0.16 | 0.15 | 0.69 | 0.43 | 0.15 |

SOURCE: Propane/Canada, Sept. - Oct. 1980, p. 32.

TABLE 5.6

GASOLINE AND PROPANE PRICE - TRANSPORTATION SECTOR:
APRIL, 1980
(all figures rounded to nearest ¢ cent)

| Province | Gasoline[a] | | | Propane[b] | | |
|---|---|---|---|---|---|---|
| | ¢/litre | $/GJ | Road Tax Included ¢/litre | ¢/litre | $/GJ | Road Tax Included ¢/litre |
| B.C. | 22 | 6.29 | 4 | 16 | 6.54 | 3 |
| Alta. | 17 | 4.82 | zero | 9 | 3.71 | zero |
| Sask. | 22 | 6.29 | 4 | 16 | 6.29 | 4 |
| Man. | 21 | 6.16 | 4 | 17 | 6.55 | 4 |
| Ont. | 22 | 6.48 | 5 | 14 | 5.52 | zero |
| Que. | 22 | 6.23 | 4 | 19 | 7.58 | 4 |
| N.B. | 23 | 6.54 | 4 | 23 | 8.96 | 6 |
| N.S. | 23 | 6.54 | 5 | 26 | 8.45 | 5 |
| P.E.I. | 23 | 6.54 | 5 | 20 | 7.75 | 5 |
| Nfld. | 26 | 7.56 | 6 | 25 | 9.65 | 6 |

SOURCE: Canadian Resourcecon Ltd., The Demand for Propane in Canada, 1980 - 1990, Vol. I, Calgary and Vancouver, 1980, p. 67.

[a]Prices are representative pump prices for regular grade gasoline less 3.3¢/litre; this latter figure is an estimate of the discount which would apply to bulk users such as fleet customers. This discount is made up of the 1.54¢/litre federal excise tax which commercial users do not pay plus an additional 1.76¢/litre reduction given to bulk consumers by the refiner. The gasoline price includes the provincial road tax and the federal sales tax of 9% of the refinery price.

[b]Fleet users of propane for carburetion are assumed to pay the same price for propane as larger users in the commercial, agricultural and industrial sectors (see Table III-22) except that federal sales tax of 9% of the gas plant or refinery price will be added to the price. In addition, road taxes as shown are included in the bulk propane prices which are illustrated. The Nova Scotia figure is the price for bulk motor fuel as specified by the Board of Commissioners of Public Utilities.

TABLE 5.7

PROJECTED PROPANE CONVERSIONS: ALL LEVELS OF GOVERNMENT

| Government | 1980 | 1985 | 1990 |
|---|---|---|---|
| Federal vehicles | 50 | 11 000 | 15 000 |
| Provincial vehicles | 100 | 2 400 | 4 800 |
| Municipal vehicles | 20 | 2 200 | 4 700 |
| Total no. of propane-powered government vehicles | 170 | 15 600 | 25 000 |
| Volume of propane use ($m^3$/year)[a] | 1 160 | 106 463 | 170 023 |
| **By Province** | **1980** | **1985** | **1990** |
| | Propane use per year ($m^3$)[b] | | |
| Atlantic Canada | 268 | 17 002 | 23 041 |
| Quebec | - | 21 769 | 30 191 |
| Ontario | 540 | 27 966 | 47 670 |
| Manitoba | - | 9 852 | 16 689 |
| Saskatchewan | - | 9 852 | 12 712 |
| Alberta | - | 9 534 | 15 890 |
| British Columbia | 334 | 10 487 | 23 835 |
| Total[c] | 1 152 | 106 463 | 170 023 |

SOURCE: Propane/Canada, Sept. - Oct., 1980, p. 37.

[a]Assumes 6.82 $m^3$/year of propane per vehicle throughout the period.

[b]Distribution by province is based on assumed propane availability across Canada by 1990, population, and government programs.

[c]May not add up due to rounding.

to 90,000 by 1990. Additional conversions may come from privately-owned vehicles.

Total propane vehicle demand, disaggregated for all provinces, is shown in Table 5.8.[13] It should be noted that here the use of propane has been projected to increase, especially in Ontario, the province with the largest commercial vehicle fleet. According to this forecast, propane use in transportation in Ontario is expected to almost double between 1981 and 1982 and then more than double again by the middle of the decade. For the rest of the 1980's the use of propane is assumed to change only slightly. In other provinces, the use of propane in transportation is also assumed to rise, notably in Alberta and Saskatchewan. For the whole of Canada, very high growth rates of propane use in transportation are forecast for 1982 and 1983.

Table 5.9 shows a projection of propane use for all sectors of the economy. It is interesting to note that, as far as the use of propane is concerned, the transportation sector is the only growing sector. The residential, industrial, and agricultural sectors which account for most of current usage are forecast to decrease their shares, and the commercial sector to stay more or less constant. The total use of propane in Canada is forecast to rise by 30 percent between 1981 and 1990, which implies an annual compounded growth rate of 2.66 percent (or 3.3 percent average per year). For comparison, the National Energy Board forecasts an average annual growth rate of propane consumption of 5.5 percent.[14]

Could domestic production of propane support such growth rates in its utilization? In this regard it is worth noting that the various available forecasts of future Canadian propane supply and demand vary appreciably, ranging from prediction of a deficit position by 1990 to continuation of more or less the current trend whereby Canadian domestic use accounts for only a half (or less) of overall output. Table 5.10 shows the latest NEB-estimated propane supply for the time period in question for various regions of the country. Table 5.9 (demand estimate) can be compared with Table 5.10 (supply estimate). From these tables it appears that adequate supplies should be available to satisfy the growth in domestic propane demand. The approximate historical relationship of only about one-half of total propane output accounting for all of domestic demand also seems to continue through the decade, although greater exportable surplus is forecast for the first half of the 1980's.

When comparing available forecasts, however, one may have difficulty in reconciling their variations. Fundamental differences

TABLE 5.8

"BUSINESS-AS-USUAL" FORECAST OF TOTAL DEMAND FOR PROPANE
($m^3$ per day)

| | B.C. | Alta. | Sask. | Man. | Ont. | Quebec and Atlantic Provinces | CANADA[a] |
|---|---|---|---|---|---|---|---|
| 1981 | 59 | 121 | 51 | 21 | 499 | - | 750 |
| 1982 | 108 | 226 | 95 | 40 | 917 | - | 1 387 |
| 1983 | 151 | 312 | 135 | 54 | 1 256 | - | 1 908 |
| 1984 | 184 | 375 | 162 | 67 | 1 513 | - | 2 302 |
| 1985 | 218 | 444 | 191 | 78 | 1 773 | - | 2 703 |
| 1986 | 242 | 490 | 212 | 86 | 1 948 | - | 2 977 |
| 1987 | 267 | 539 | 232 | 94 | 1 948 | - | 3 258 |
| 1988 | 270 | 545 | 235 | 95 | 2 134 | - | 3 280 |
| 1989 | 275 | 550 | 239 | 97 | 2 140 | - | 3 301 |
| 1990 | 278 | 557 | 242 | 97 | 2 150 | - | 3 324 |

(To obtain the above volumes in barrels, use 1 bbl = 0.15899 $m^3$.)

[a]Totals may not add up due to rounding.

SOURCE: Canadian Resourcecon, op. cit., p. 233.

TABLE 5.9

"BUSINESS-USUAL" - SECTORAL PROPANE DEMAND FORECAST: CANADA
($m^3$ per day)[a]

| Year | Residential | Commercial | Industrial | Agriculture | Transportation | Total |
|---|---|---|---|---|---|---|
| 1981 | 2 137 | 2 177 | 1 354 | 532 | 751 | 6 893 |
| 1982 | 2 054 | 2 185 | 1 262 | 522 | 1 387 | 7 410 |
| 1983 | 1 942 | 2 101 | 1 178 | 509 | 1 908 | 7 637 |
| 1984 | 1 886 | 2 100 | 1 125 | 499 | 2 302 | 7 912 |
| 1985 | 1 820 | 2 096 | 1 097 | 485 | 2 703 | 8 201 |
| 1986 | 1 810 | 2 137 | 1 079 | 478 | 2 977 | 8 479 |
| 1987 | 1 798 | 2 175 | 1 073 | 467 | 3 258 | 8 771 |
| 1988 | 1 790 | 2 208 | 1 075 | 459 | 3 280 | 8 812 |
| 1989 | 1 781 | 2 251 | 1 087 | 448 | 3 301 | 8 867 |
| 1990 | 1 769 | 2 306 | 1 099 | 434 | 3 323 | 8 931 |

SOURCE: Canadian Resourcecon, op. cit., p. 9.

[a]To obtain the above values in barrels, use 1 bbl = 0.15899 $m^3$.

TABLE 5.10

PROPANE PRODUCTION: NEB FORECAST
($m^3$ per day)

| Province | | 1981 | 1985 | 1990 |
|---|---|---|---|---|
| B.C. | gas plants | 215 | 210 | 153 |
| | refineries[a] | 325 | 360 | 391 |
| | Total | 540 | 570 | 544 |
| Alberta: | gas plants | 15 494 | 13 086 | 8 905 |
| | refineries[b] | 982 | 1 121 | 1 214 |
| | Total | 16 476 | 14 207 | 10 119 |
| Saskatchewan: | gas plants | 161 | 113 | 74 |
| Ontario: | refineries | 1 305 | 1 267 | 1 211 |
| Quebec: | refineries | 818 | 792 | 871 |
| Maritimes: | refineries | 391 | 383 | 322 |
| Supplies from unconnected established reserves & additions | | 759 | 4 442 | 3 079 |
| Total Canada | | 20 450 | 21 774 | 16 220 |

(To obtain the above values in barrels, use 1 bbl = 0.15899 $m^3$.)

SOURCE: NEB, Canadian Energy, Ottawa: Minister of Supply and Services Canada, June, 1981, Appendices Q and R.

[a]Includes B.C., Yukon and N.W.T.

[b]Includes Alberta, Saskatchewan and Manitoba.

exist between the views expressed by some of the submittors regarding future supply and utilization of propane during last year's NEB hearings, and the view of the Board itself. While Dome Petroleum, Petro-Canada and Shell Canada all believed that the Canadian supply of propane (and butanes) during 1981 and 2000 would exceed domestic demand, the Board's own view was that such will be the case only until after 1985. Table 5.11 indicates the Board's projected deficit for propane resulting from "the termination of cycling schemes and the reduction in both solution gas and natural gas production volumes...."[15] To illustrate the divergent views of the various submittors, Table 5.12 shows their forecast of growth rates of demand for total LPG.[16] It can be seen that much higher rates are forecast for the current decade, with an average rate of growth of 4.5 percent per year. Although the forecasts agree on the growth of domestic demand for propane, no agreement exists regarding exports. While U.S. demand is generally expected to strengthen, new supplies from the Middle East, the North Sea,

TABLE 5.11

PROPANE SUPPLY/DEMAND BALANCE: NEB PROJECTION
(cubic metres per day)[a]

| Year | Supply | Demand | | | Surplus or Deficity |
|---|---|---|---|---|---|
| | | Canada[b] | Net Export Licences | Total | |
| 1981 | 20.6 | 9.4 | 2.2 | 11.7 | 9.0 |
| 1982 | 22.4 | 9.5 | 2.1 | 11.6 | 10.8 |
| 1983 | 22.2 | 10.2 | .8 | 11.0 | 11.2 |
| 1984 | 22.7 | 10.3 | .8 | 11.1 | 11.6 |
| 1985 | 22.0 | 10.6 | .8 | 11.4 | 10.6 |
| 1990 | 16.4 | 17.1 | .7 | 17.8 | - 1.4 |
| 1995 | 14.9 | 19.6 | 0 | 19.6 | - 4.7 |
| 2000 | 14.1 | 19.8 | 0 | 19.8 | - 5.7 |

SOURCE: NEB, Canadian Energy, op. cit., Table 16-5, p. 220.

[a]See the source of the table for values in petajoules.

[b]Includes propane used in tertiary recovery schemes.

TABLE 5.12

FORECASTS OF CANADIAN DEMAND FOR LPG: ANNUAL GROWTH RATES
(percent)

| | 1980-1990 | 1990-2000 | 1980-2000 |
|---|---|---|---|
| Canadian Petroleum Association | 6.5 | - | - |
| Dome Petroleum | 1.7 | 1.7 | 1.7 |
| Gulf Canada[a] | 10.0 | -5.6 | 1.9 |
| Imperial Oil | 3.4 | 2.2 | 2.8 |
| Petro-Canada[a] | 4.8 | 0.2 | 2.5 |
| Shell Canada[a] | 1.1 | 0.6 | 0.9 |
| Texaco Canada | 6.0 | 3.4 | 4.7 |

SOURCE: NEB, Canadian Energy, op. cit., p. 88, Table 7-28.

[a]Supplemental forecast.

Indonesia and Mexico may create strong competition for Canadian propane in that market. Much will depend on the price of those new propane supplies. If attempts by some exporters to push LPG prices towards equivalent oil product levels succeed, the current incentive to switch to the use of propane as a relatively cheaper fuel will be erased.

Not surprisingly then, one of the chief problems in accurately predicting future propane use is the uncertainty surrounding future propane price. If the use of propane in transportation is to (nearly) quadruple by 1985, as forecast in Table 5.8, then a vast investment will have to be undertaken to upgrade the propane distribution network, which will not leave the price of propane unaffected. Thus the future use of propane in transportation and elsewhere in the economy may be facing two limiting factors. One is domestic supply as forecast by some, and the other is a likely increase in cost, which would wipe out some of the cost-advantage that propane is presently enjoying relative to gasoline.

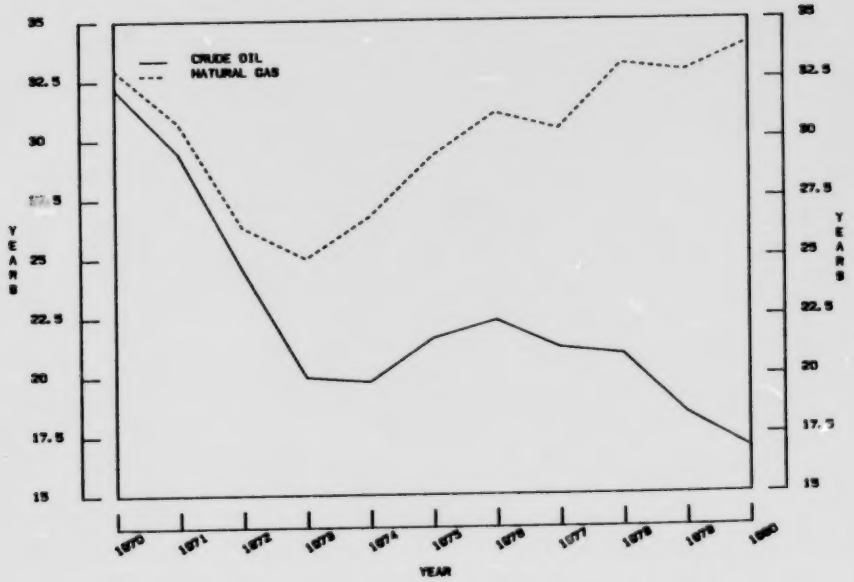
## 5.5 Compressed Natural Gas

The first factor clearly distinguishing CNG from the other alternative fuels discussed in this chapter is the availability of supply. Canada has large reserves of natural gas relative to the level of annual consumption, and it also has a vast potential in terms of new gas discoveries in both the western Canadian sedimentary basin and in frontier areas.

In 1980 Canadian consumption of natural gas was 54.7 billion $m^3$ (1.93 TCF)[17] per year. The life index for Canadian crude oil and natural gas reserves is shown in Figure 5.1; it refers to the number of years that conventional reserves will last at current annual rates of consumption (domestic and exports).[18] It can be seen that proven marketable reserves of natural gas will last some 34 years at the present level of extraction. In addition to proven reserves, new discoveries are expected to be made which will increase the life index levels for gas. At the end of 1980, total Canadian proven reserves of marketable natural gas stood at 2.49 trillion $m^3$ (87.96 TCF)[19] and it has been suggested that, during the 1980's, a further 12.18 trillion $m^3$ (430 TCF) of marketable natural gas (average expectation) may be discovered.[20]

To put these supply (reserves) estimates into perspective with possible demand resulting from conversions to CNG, it has been estimated that if all of Canada's vehicles are converted to CNG, a little over 1 TCF (0.028 trillion $m^3$) of natural gas would be needed in addition to current demand.[21] More realistically, though, 500,000 heavily-travelled vehicles (some 4 to 5 percent of total) could be converted to CNG requiring only about 2.83 billion $m^3$ (0.1 TCF) of additional natural gas.[22] These figures suggest that if CNG were to be used as a transportation fuel, supply would certainly not be a problem, in fact the current problem of shut-in natural gas[23] could be alleviated considerably.

The second factor distinguishing CNG from the other alternative fuels is the fact that a good part of the necessary distribution network is already in place in the form of the existing natural gas pipeline network across Canada. Existing natural gas lines, as well as those under construction or proposed, are shown in Figure 5.2. A compressor to turn natural gas into CNG can be placed anywhere along an existing natural gas pipeline network, with obvious advantages relative to other fuels discussed in this chapter. Since most of Canada's main consuming areas are already serviced by natural gas, or will soon be serviced (parts of Quebec and the Maritimes), CNG has a competitive advantage over the other alternatives, certainly as far as distribution is concerned. At time of writing, however, CNG was being sold only at three Husky Oil service stations in Calgary, Edmonton and Vancouver, though negotiations were under way to market CNG in Ontario (10 service stations in Toronto alone) and in Quebec. Research is also currently under way on a driver-owned small compressor which would fill the vehicle tank slowly over night via a line run off the home heating service gas line.




SOURCE: Canadian Enerdata, op. cit., p. 23

FIGURE 5.1: LIFE INDEX OF CANADIAN OIL AND GAS RESERVES

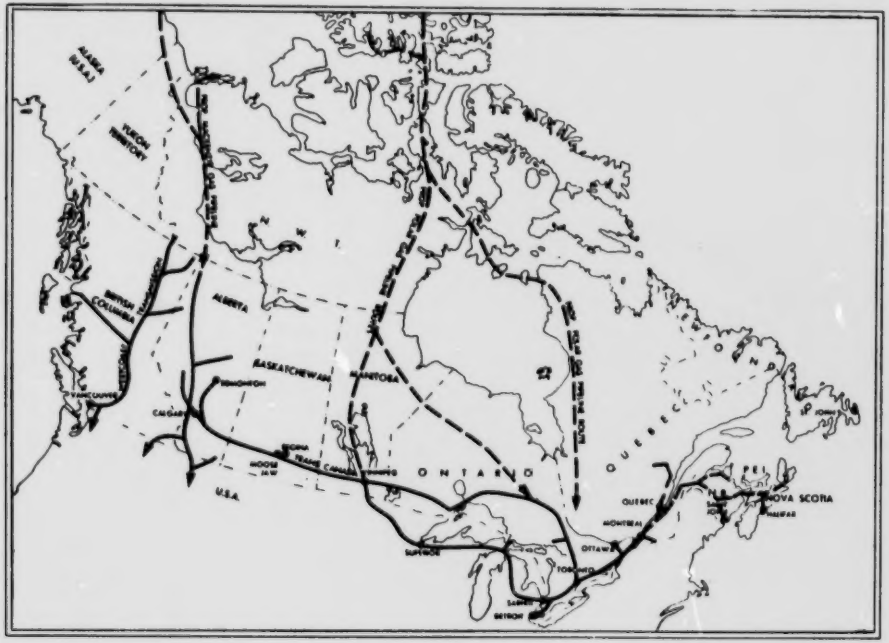



FIGURE 5.2: EXISTING AND PROPOSED NATURAL GAS PIPELINES IN CANADA.

The current number of vehicles operating on CNG in Canada is relatively small - only 60 or 70 cars - but CNG Fuel Systems expects conversions to increase rapidly now that a conversion grant ($600 per vehicle) has been introduced to make CNG conversions comparable in cost to those to propane. It is expected that at least 4,000 cars and optimistically as many as 11,000 will be converted to CNG during 1982.[24] The potential to 1990 is, of course, much larger. Possibly more than 10 percent of all vehicles could then be CNG-fuelled if market conditions allow competition among the alternatives strictly on the basis of availability and cost.

## 5.6 Concluding Comment

Four alternative transportation fuels have been discussed in this chapter with regard to their possible future utilization levels and likely supply constraints. These were: methanol, ethanol, propane and compressed natural gas.

Although Canada has plentiful resources to produce both methanol and ethanol, these fuels will most likely be used within this decade only as extenders of gasoline supplies should shortages of crude oil develop; or they could be produced and used in those parts of the country where no refining of crude oil takes place and where indigenous resources for their production can be found. The one distinct advantage of resources suitable for the production of these two fuels is that they are much more evenly distributed across Canada than hydrocarbons, although their energy 'density' is lower.

Propane and CNG are much more promising as alternatives to gasoline in transportation during this decade. There is some disagreement among available forecasts as to the adequate supply of propane if a large switch from gasoline to propane were to materialize, but there seems to be no natural gas supply problem if CNG demand for transportation use were to accelerate sharply.

If the switch to alternative transportation fuels is to be carried out in an efficient manner, the winners and losers should be determined in the marketplace on the basis of cost and supply availability. While the costs of propane and CNG as alternative transportation fuels are the lowest of the fuels discussed, a conclusion drawn from the analysis in this chapter is that only CNG would be free of any supply-side restrictions in the main consuming areas of Canada.

**Footnotes**

[1]G. A. Constable, "Propane Carburetion - Future Potential", paper presented to Propane Gas Association of Canada, 1981 Convention, June 1, 1981, p. 2. The commercial vehicle market is diverse, including urban service vehicles, pickup and delivery fleets, taxis, school buses and the like.

[2]Canadian Energy Trends, Toronto: Canadian Enerdata Ltd., 1981, Vol.1/No. 1.

[3]Principle biomass (renewable) resources include pulp and paper, lumber and plywood mills residues and waste products, straw, animal manure, farm woodlots, logging residues, surplus and deserted wood, and energy plantations. Peat is also sometimes included in biomass although it is, like fossil fuels, non-renewable. Municipal solid waste is not a form of primary biomass resource. It is a result of social and industrial activity which requires continual use or disposal with very little potential for storage.

[4]Energy, Mines and Resources Canada, Biomass Energy in Canada, Report ER 80-4E, prepared by P. Love, Middleton Associates, Ottawa: Minister of Supply and Services, 1980, p. 2.

[5]Peat has been excluded from the estimate.

[6]See for instance R. Overend, "Briefing on Biomass Energy Potentials", submitted to the Parliamentary Task Force on Alternative Energy, July, 1980, reprinted in the Minutes of Proceedings and Evidence of the Special Committee on Alternative Energy and Oil Substitution, House of Commons, Issue No. 3, July 8, 1980, p. 3A:3.

[7]Ontario, The Ministry of Energy, Economic Analysis of Synthetic Liquid Fuels, op. cit., vol. 2, p. 4.

[8]A. E. Meyer, R.D.C. Research, Development & Consulting Ltd., "Gasohol Production", a paper presented at a CERI Seminar on Alternative Transportation Fuels, Calgary, Nov. 19, 1981.

[9]See Propane/Canada, Sept. - Oct., 1981, p. 32.

[10]Propane/Canada, Sept. - Oct., 1980, p. 34.

[11]See, Ontario, Ministry of Energy, "Drive: Propane" booklet, 1981; and a statement by Dr. B. Yang of the Ministry's conservation and renewable energy group in Canadian Energy News, CCH Canada Ltd., April 15, 1982, pp. 62-63.

[12]Propane/Canada, Sept. - Oct., 1980, p. 39, Table 9.

[13]Note that Table 5.8 does not assume any use of propane in Atlantic Canada and Quebec in the 'Business-as-Usual' case. Tables C.1

and C.2 in Appendix C show the "High Penetration" case with projected propane conversions across Canada.

[14]The NEB, Canadian Energy, op. cit., p. 220.

[15]NEB, Canadian Energy, op. cit., pp. 220-222. Note the differences in projected total domestic use between Tables 5.11 and 5.9. To make Tables 5.9, 5.10 and 5.11 comparable, all values have been translated into cubic metres. Since values in Table 5.10 are in the original source in $m^3$/day and those in Table 5.11 in petajoules/year, a slight discrepancy resulted once these values have been translated into cubic metres per year in Tables 5.10 (Total Canada) and 5.11 (Supply).

[16]Including propane and butanes.

[17]Canadian Energy Trends, op. cit., p. 29; does not include exports.

[18]The index refers to marketable reserves only.

[19]CPA estimate, reprinted in Canadian Energy Trends, op. cit., p. 21.

[20]R. M. Procter, P. J. Lee and D. N. Skibo, "Canada's Conventional Oil and Gas Resources", Calgary: ISPG, Geological Survey of Canada, EMR, 1981, p. 24.

[21]The Hon. J. Buchanan, "The Role of CNG Fuel Systems Ltd. in the Development of CNG as a Motor Vehicle Fuel", paper presented at the World Conference on Methane as a Motor Vehicle Fuel, Vancouver, Sept. 28-29, 1981, p. 6.

[22]R. E. Wyman, "Canadian and Overseas Activities and Research Regarding Methane Powered Vehicles", op. cit., p. 13.

[23]Shut-in gas refers to discovered natural gas reserves which are currently shut in the ground due to lack of (export/domestic) markets.

[24]The Hon. J. Buchanan, CNF Fuel Systems' president quoted in The Calgary Herald, Jan. 22, 1981.

# APPENDIX A

# COST ASSUMPTIONS

## Appendix A

## COST ASSUMPTIONS

The various cost assumptions employed in the analysis are as follows:

(i) All costs are expressed in 1981 Canadian dollars.

(ii) The exchange rate between the U.S. and Canadian dollar:

| | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|
| C$/US$ | 1.06 | 1.14 | 1.17 | 1.17 | 1.18 |

(iii) The annual inflation rate in Canada (the average of CPI and industrial selling price index):

| 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|
| 9.3 | 9.2 | 9.0 | 9.0 | 9.6 |

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Sources for (ii) and (iii): Bank of Canada Review, April 1981, tables 62, 63 and 65.

# APPENDIX B

# PLANT CONSTRUCTION AND OPERATING COSTS

## Appendix B

## PLANT CONSTRUCTION AND OPERATING COSTS

### B.1 A Methanol Plant - Estimated Expenditures (Methanol from Coal)

(a) Assumptions:

- 330 operating days per year - 25 years;
  Inputs: 37,985 tons of coal feed per day (4.4% sulfur, Illinois-type coal);
- 758,000 Kwh of electricity a day; 24.53 acre - feet of water per day;
  Outputs: 103,750 barrels of methanol per day; 1,460 tons of sulfur per day;
- location: could be nearly anywhere but should be near a coal mine;
- there are 10 parallel trains, each having 3 Koppers-Totzek gasificers and a methanol synthesis section;
- overall thermal efficiency is expected around 38% (based on daily coal input of some $0.775 \times 10^{12}$ Btu and daily methanol output of about $0.295 \times 10^{12}$ Btu;

| (b) Capital Costs | US $ Million (Jan. 1980) |
|---|---|
| Construction | 2,421.8 |
| Land and Land Rights | 4.9 |
| Base Year Value of Escalation and Interest During Construction | 169.4 |
| Working Capital | 387.9 |
| Total | 2,984.0 |

| (c) Annual Operating Costs | |
|---|---|
| Manpower | 71.3 |
| Materials and Parts | 62.0 |
| Utilities | 7.4 |
| Ad Valorem Taxes | 30.4 |
| Insurance | 18.2 |
| Rents, Royalties, Leases | 4.2 |
| Miscellaneous | 6.3 |
| Feedstock: coal (at US $23.10/ton) | 289.5 |
| Byproduct Credits: sulfur (at US $26.85/ton) | -13.0 |
| Total | 476.3 |

SOURCE: Bechtel Corp. USA, published in R. H. Shackson and H. J. Leach, op. cit., p. 76.

**B.2 An Ethanol Plant - Estimated Expenditures (Ethanol from Corn)**

(a) Assumptions:

- 330 operating days per year - 25 years;
  Inputs: 58,900 bu. of corn per day; 14.15 acre-feet of water per day; 199,500 kwh of electricity per day;
- Outputs: 3,607.5 barrels of alcohol per day; 536.7 tons of distiller's dry grains per day; 31.6 tons of ammonium sulfate per day;
- location should be in a corn-producing area and near source of coal;
- total energy efficiency of a plant of this type is around 56%*;

| (b) Capital Costs | US $ Million (Jan. 1980) |
|---|---|
| Construction | 70.5 |
| Land and Land Rights | 0.6 |
| Base Year Value of Escalation and Interest During Construction | 3.1 |
| Working Capital | 10.8 |
| Total | 85.0 |

| (c) Annual Operating Costs | |
|---|---|
| Manpower | 4.4 |
| Materials and Parts | 3.3 |
| Utilities | 2.5 |
| Ad Valorem Taxes | 1.1 |
| Insurance | 0.6 |
| Rents, Royalties, Leases | 0.2 |
| Miscellaneous | 6.2 |
| Feedstock: | |
| corn (at US $2.80/bu.) | 54.6 |
| coal (at US $29.90/ton) | 3.0 |
| Byproduct Credits: | |
| dry grains (at US $135.00/ton) | -23.4 |
| amonium sulfate (at US $19.00/ton) | - 0.5 |
| Total | 52.0 |

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SOURCE: Bechtel Corp. USA, published in R. H. Shackson and H. J. Leach, op.cit., p. 76.

*Energy efficiency figure obtained form T.O. Wagner et al., op.cit., p. 257. For an interesting discussion of the question of energy balance of gasohol, see R. S. Chambers et al. "Gasohol: Does It or Doesn't It Produce Positive Net Energy?", Science, Nov. 16, 1979, pp. 789-795.

# APPENDIX C

# ALTERNATIVE FORECAST SCENARIOS

TABLE C.1

"HIGH PENETRATION" FORECAST OF TOTAL VEHICLE DEMAND FOR PROPANE
(cubic metres per day)

| | B.C. | Alta. | Sask. | Man. | Ont. | Que. | N.B. | N.S. | PEI | Nfld. | Canada |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 126 | 202 | 127 | 78 | 661 | 215 | 32 | 43 | 8 | 25 | 1 516 |
| 1982 | 310 | 496 | 313 | 188 | 1 616 | 524 | 78 | 102 | 19 | 60 | 3 706 |
| 1983 | 461 | 706 | 466 | 281 | 2 388 | 777 | 114 | 151 | 25 | 89 | 5 488 |
| 1984 | 618 | 984 | 623 | 375 | 3 167 | 1 033 | 151 | 203 | 37 | 119 | 7 309 |
| 1985 | 703 | 1 114 | 707 | 426 | 3 569 | 1 170 | 173 | 232 | 40 | 137 | 8 271 |
| 1986 | 771 | 1 212 | 771 | 467 | 3 877 | 1 274 | 189 | 254 | 45 | 149 | 9 010 |
| 1987 | 782 | 1 228 | 782 | 474 | 3 896 | 1 286 | 191 | 256 | 46 | 151 | 9 091 |
| 1988 | 793 | 1 241 | 790 | 478 | 3 914 | 1 297 | 194 | 261 | 46 | 153 | 9 165 |
| 1989 | 804 | 1 254 | 799 | 486 | 3 934 | 1 305 | 197 | 266 | 48 | 156 | 9 248 |
| 1990 | 817 | 1 266 | 810 | 493 | 3 957 | 1 316 | 267 | 267 | 48 | 159 | 9 331 |

TABLE C.2

"HIGH PENETRATION" SECTORAL PROPANE DEMAND FORECAST: CANADA
(cubic metres per day)

| Year | Residential | Commercial | Industrial | Agriculture | Transportation | Total |
|---|---|---|---|---|---|---|
| 1981 | 2 910 | 2 446 | 1 341 | 536 | 1 516 | 8 749 |
| 1982 | 3 565 | 2 745 | 1 359 | 531 | 3 706 | 11 906 |
| 1983 | 4 176 | 3 020 | 1 315 | 529 | 5 48[illegible] | 14 528 |
| 1984 | 4 835 | 3 300 | 1 308 | 523 | 7 309 | 17 276 |
| 1985 | 5 495 | 3 594 | 1 322 | 521 | 8 271 | 19 202 |
| 1986 | 6 198 | 3 851 | 1 357 | 514 | 9 010 | 20 930 |
| 1987 | 6 875 | 4 121 | 1 394 | 511 | 9 091 | 21 996 |
| 1988 | 7 564 | 4 383 | 1 450 | 504 | 9 165 | 23 066 |
| 1989 | 8 190 | 4 651 | 1 510 | 500 | 9 248 | 24 100 |
| 1990 | 8 808 | 4 878 | 1 571 | 493 | 9 331 | 25 082 |

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